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elements, each element consisting of two vertical rows of parallel tubes having upward and opposite inclinations of about three degrees. Horizontal end coupling boxes connect together the various tubes composing the layers of the elements, and the upper ends of the tubes open into a steam drum which is traversed by the feed-water inlet pipe. Over the main boiler, and under the same casing, is arranged a separate group of horizontal tubes in which the steam generated in the main boiler is dried. The draught is automatically controlled by the variations of the steam pressure, and a special design of grate bar is adopted to ensure a uniform passage of air through the fire. As good examples of multitubular steam generators based on the Belleville principles may be mentioned those of Le Blanc, Pinette, Hermann-Lachapelle, Ruyter, Champeaux, Basiliades, Rikkers, Roser, Baxter, Thomas and Laurens, Duchesne, Farcot, Dulac, Girard, Galloway, Niclausse, and many others.

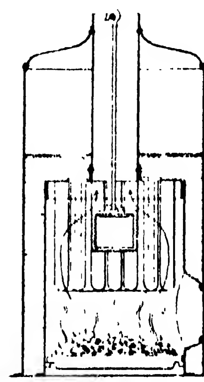


Fig. 10. Vertical Boiler with Suspended Field Tubes.

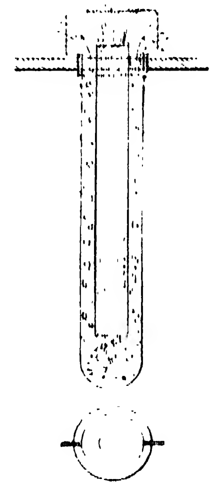


Fig. 11. Section of Field Tube.

Certain boilers are provided with suspended tubes of the form illustrated in fig. 7, or of the Field type illustrated in figs. 10 and 11. The lower ends of the outer tubes, which hang downwards into the fire box, are closed so that the water is compelled to circulate down the small central tube to the bottom and up the outer annular space between them to the top, where a baffle-plate arrangement causes it to spread outwards in all directions. Excellent steaming results are obtained from the use of Field tubes, but the wear due to burning of the ends is excessive, as the circulation frequently becomes obstructed.

CLASS IV.—RAPID-CIRCULATION BOILERS

These boilers are designed to give the greatest heating surface in a given size of boiler. Relatively to their great evaporative power they contain the least possible quantity of water, and consequently the regulation of the feed water is very difficult and important.

Among the many kinds which have stood the test of service may be mentioned the Du Temple boiler used in torpedo boats of the French navy. It consists of crossed spiral tubes around which the furnace gases play. The type has been improved by Herreshoff, who, according to a statement by Mr. H. de Parville, has constructed a generator capable of evaporating 175 lb. of water per hour under a pressure of 37 lb. per square inch. The entire engine with its cylinder and all accessories does not weigh more than 50 lb., and can develop 6 h.p. at a speed of 450 revolutions per minute.

The boiler invented by Count de Dion and constructed by M. Bouton has also a great evaporative power relatively to its weight. It consists of a series of small tubes

inclined slightly to the horizontal, and arranged in circular layers one above the other, and radiating from a common centre. The fire is completely enclosed, thus ensuring the direct application of the heat.

Fig. 13 shows a somewhat similar type designed by Hérisson. Boilers of this kind

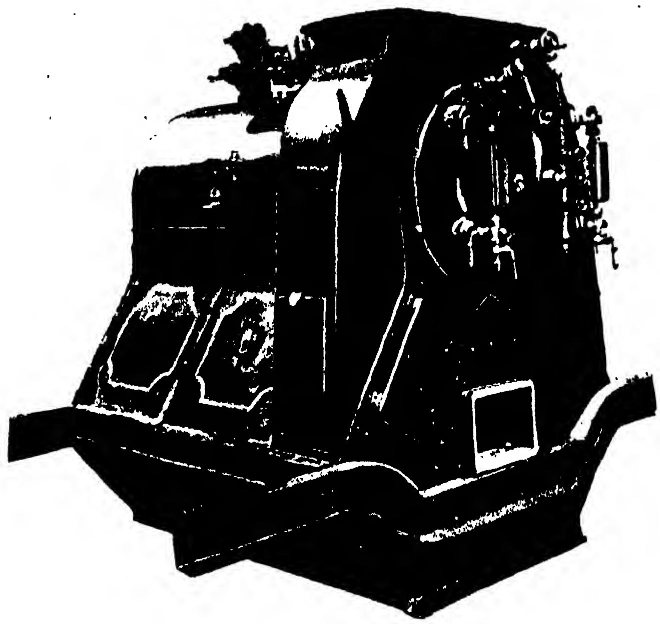


Fig. 12.—Roser Semi-tubular Boiler

have been found to give more satisfactory results when used for industrial purposes than when used for motor-car or similar work. Spiral-tube boilers have been strongly advocated by many manufacturers, but results have not proved their superiority to other multitubular boilers, and now they are not frequently used.

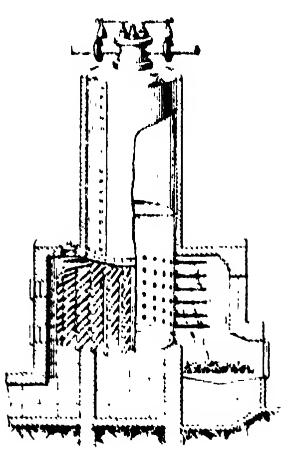


Fig. 13. The Herisson Tubular Boiler

In the Serpollet boiler the tubes contain a very minute quantity of water at any moment, and therefore have the advantage of being inexplodable. Instead of carrying a store of water and steam for the engine, boilers of the Serpollet type depend upon the carrying of a store of heat sufficient for the vaporization of the water as it is required. The tubes have very thick walls in comparison with the internal water space, and thus hold a large quantity of heat and a small quantity of water. In section they have the form of an inverted **U** with walls about 3/8 in. thick, and are placed in direct contact with the furnace gases. A constant current of water is forced through the tubes and is almost instantly vaporized. With such a system steam may be very rapidly raised, and the weight of the boiler is small, while the security against explosion is complete however great the steam pressure. As the calorific efficiency is also good, these boilers have been applied to many services where rapid steam-raising qualities are required. For example, they have been used on certain of the Paris tram

cars and for fire engines. A still further improvement, made by a French engineer, M. Chatenet, has been experimented upon in England with good results. Instead of carrying a store of water—or even, as Serpollet does, instead of forcing a continual thin stream through the pipes Chatenet introduces the water in a finely divided or atomized condition into the tubes, where it flashes into vapour. The atomizing of the water is done by a small force pump, which forces a jet of water against an edge, and thus breaks it up into a fine spray. As the boiler contains practically no water its dimensions are small for a large evaporative power, and the construction is not complicated. Further, the danger of explosion is negligible, as in the Serpollet and other flash boilers, owing to the absence of a large body of water at a high temperature, which is converted into steam with explosive force whenever the pressure is suddenly relieved.

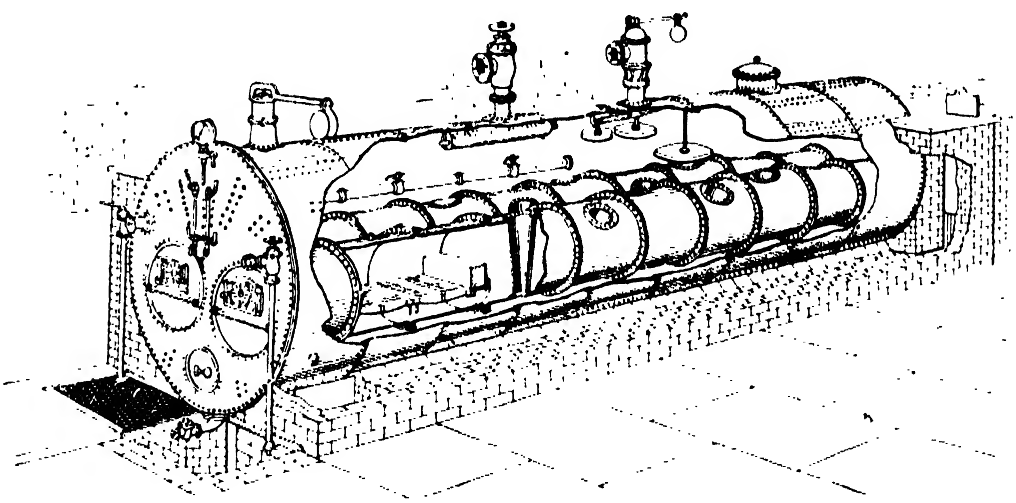


Fig. 14.—Galloway Lancashire-type Boiler with Two Furnaces

From theoretical considerations it might be expected that the tubes would be readily burned, owing to the absence of water. Experience has shown, however, that there is no excessive tendency to burning in this way. The atomized water apparently suffices to keep the tubes at a uniform temperature, and it is found that a thin film of water forms upon the surfaces and protects them from the direct action of the flames.

Having distinguished the different classes of steam generators in general use, the advantages and disadvantages of various designs of boilers will now be considered.

THE ESSENTIAL FEATURES OF A GOOD BOILER

The choice of a type must primarily be determined by the working conditions; the uniformity of the demand for steam; the necessity for rapid steam raising; or the nature of the fuel. Having decided on the type, the particular make of boiler to be chosen may be determined by minor considerations. Often the reputation of the maker is a better guide than the price, and the boiler which costs least per ton weight may not be the most economical or in the end cheapest. The commercial value of a boiler is determined more by its efficiency, durability, ease of working, and small

cost of repairs than by its first cost. As a guide to the choice of a boiler, the following qualities should be looked for.

Fire Box. The fire box should be arranged to give the most complete combustion and to utilize the heat to the best advantage. In a portable engine its rigidity should be considerable, and under any circumstances it should be readily accessible and easily repaired.

Heating Surface. It is necessary that the hot gases should circulate in a direction opposite to that of the water, in order to equalize the temperature and expansion of the parts, which latter should be freely allowed for. The circulation should be rapid, and means should be taken to ensure the separation of the water from the steam.

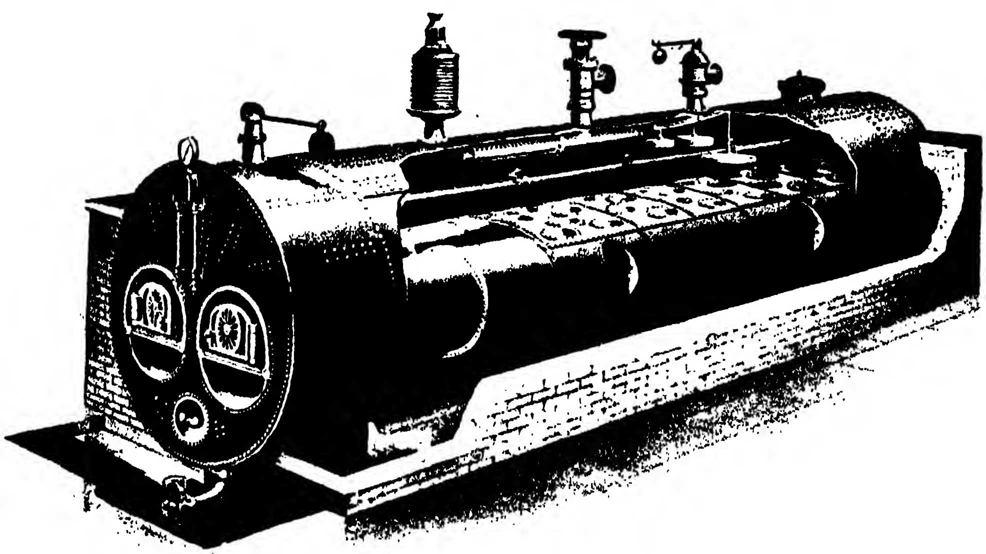


Fig. 15. Galloway Boiler, showing Galloway Tubes and Pockets.

Encrustation. The boiler should be so arranged that the insoluble deposits from the boiling water will not gather on the heated plates or in places where the removal of the mud is difficult.

Priming. It is essential that there should be no obstruction under the water surface that may cause violent surging. A steam-holder of sufficient size is also necessary to prevent water from being carried over by the steam.

Joints. These should be as few as possible and so designed that they become tighter when under internal pressure.

Price, Durability, Repairs, and Upkeep. The boiler should be of a simple form, readily accessible both externally and internally, and the parts should not be so rigid as to resist expansion and thus cause undue wearing at the joints.

Safety. Security against explosion depends largely upon the care taken during manufacture, in the installing of the boiler, and in the working. With an experienced stoker who exercises prudence and care the fear of disaster to a good boiler is negligible.

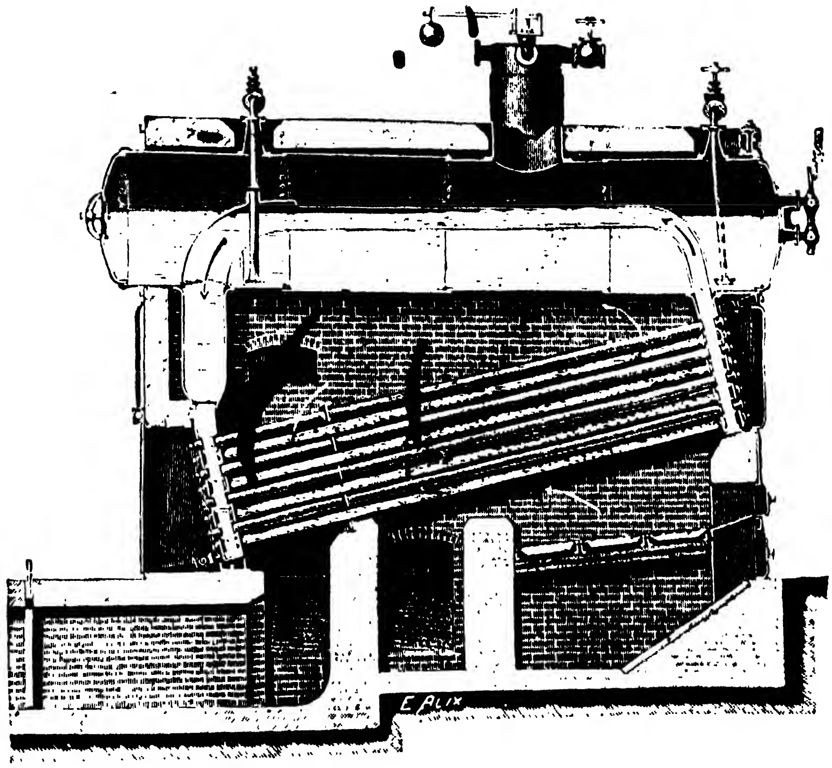


Fig. 16. - Buttner Water-tube Boiler

There are certain objections to tubular boilers which may be summarized as follows:

1. Surging of the water and priming.
2. The water tubes become encrusted internally and the fire tubes become choked with soot, and are liable to fracture when weakened by corrosion.
3. Irregularity of the steam pressure due to the smallness of the quantity of water in the boiler.
4. Complication of parts and increased liability to derangement.
5. High cost of construction.
6. Reduction of the flame and loss of heating power due to the deposit of soot.
7. Cooling of the flame before combustion is complete.
8. Reduced effective heating surface, the parts of the tubes traversed by the gases alone being effective.
9. The forced and intimate contact of the fuel and the products of combustion.
10. Obstructions preventing the rise of vapour and hindering the circulation.
11. Short travel of the hot gases.
12. Obstruction of the currents.
13. Excessive rapidity of the action.
14. Reduction of the evaporative surface in relation to the size of the furnace and the grate.

It is not necessary to dwell longer on the advantages or disadvantages of the various types, and enough has been said to distinguish the characteristics of the

boilers in general use. In the succeeding section the practical aspect will be considered; the best means of obtaining the greatest efficiency; the treatment of the fire: of the feed water supply; and the care of the water and pressure gauges, safety valves, and other accessories.

MANAGEMENT OF THE FIRE

On account of its great calorific value, coal is generally used when available.

To kindle the fire, cotton waste soaked in oil is spread over the grate together with firewood, and then ignited. To prevent the formation of dense smoke, which may choke the fire, the furnace door should be left open until the wood is well ablaze, when it must be closed. Starting the fires should be done quickly, with the damper raised, but if the boiler is new the damper should be controlled to prevent overstrain due to too rapid heating. Any signs of fracture or other defects should be immediately reported by the stoker to his chief.

When stoking, the fire door should be open for the shortest possible time and promptly closed, because each time it is opened the cold air which enters cools the walls and retards the action. As the wood is consumed, the hot embers should be spread over the grate and then coal added little by little until the fire is formed and the steam pressure has risen to 1 or 2 lb. At this pressure the damper should be opened fully, and regular fuel should be spread in uniform layers over the whole grate, leaving no black spaces.

An experienced stoker will regulate the thickness of the fire to suit the fuel: for wood or peat a thickness of about 8 in. is necessary; for coke with natural draught 12 in., and with forced draught about 16 in. to 24 in. For refuse the thickness must vary with the quality and fineness.

If on increasing the draught by opening the damper or starting the blast (when such is provided) the pressure falls, the probable reason is that the fire has been badly started or that the fuel is of poor quality. In such a case the draught must be reduced and the fire redressed, while restricting at the same time the entrance of air under the grate. Then the damper should be gradually re-opened, until the most suitable arrangement under which the pressure rises has been determined.

It is easy to observe by eye the condition of the fire. If the flames have a dull-red appearance carbon dioxide is being formed; on the other hand, a yellow-blue flame indicates the production of carbon monoxide, which gives the least favourable results.

Coals suitable for steam boilers may be divided into two classes: caking, or bituminous coals, which contain a large proportion of volatile matter; and non-caking, or anthracitic coals, which contain a much smaller proportion. When using caking coal the thickness of the fire bed should be about 3 in. to 4 in., and a little more when anthracite is used.

Anthracite is preferable to caking coal, which is liable to give rise to an objectionable amount of smoke. Continual inspection of the fire is necessary to prevent the fire

from becoming thin in places; otherwise the air will pass through these portions instead of spreading uniformly over the whole grate.

In practice the fuel should be pushed to the back end of the grate as it is coked, and new fuel added at the front to take its place. The consumption of coal depends upon the stoker. It may vary with the individual as much as thirty per cent. Certain coals contain siliceous cinders which at a high temperature cement together to form a hard clinker, especially when the air supply is not regular over the grate. It should

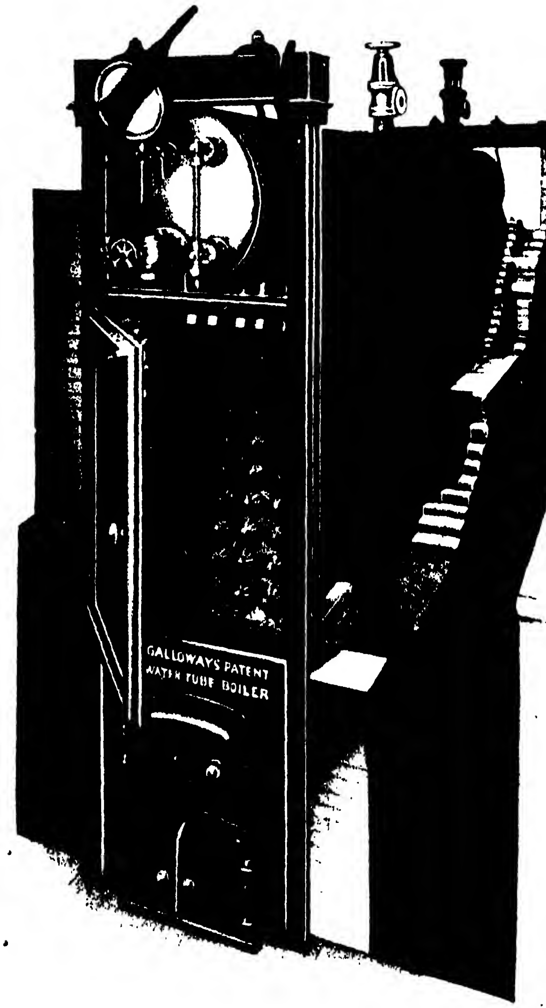


Fig. 17.—Galloway Water-tube Boiler

be regularly broken and removed, as otherwise, if allowed to form in quantity, the fire bars become rapidly burned.

Coal should be added at frequent regular intervals, say every five to ten minutes, and oftener when the fuel is wood; and the firing should be done as quickly as possible. The draught should be regulated as required by raising or lowering the damper.

If the safety valve, although properly set, commences to blow off, the strength of the fire should be reduced by opening the furnace door and lowering the damper as much as is required to reduce the pressure. In case of danger, however, the fires should be smothered or banked with non-combustible material, such as earth, or,

where this is not available, small damp dross. On no account should the fire be stirred up, or the safety valve interfered with.

The supply of feed water should be regular, and sufficient to keep the water-level in the gauge glass constant. A rise of level is not so serious as a considerable fall, which may allow the furnace crowns to become uncovered and overheated. Under these circumstances the addition of cold feed water would probably result in the instantaneous evolution of a great excess of steam and a possible explosion of the boiler.

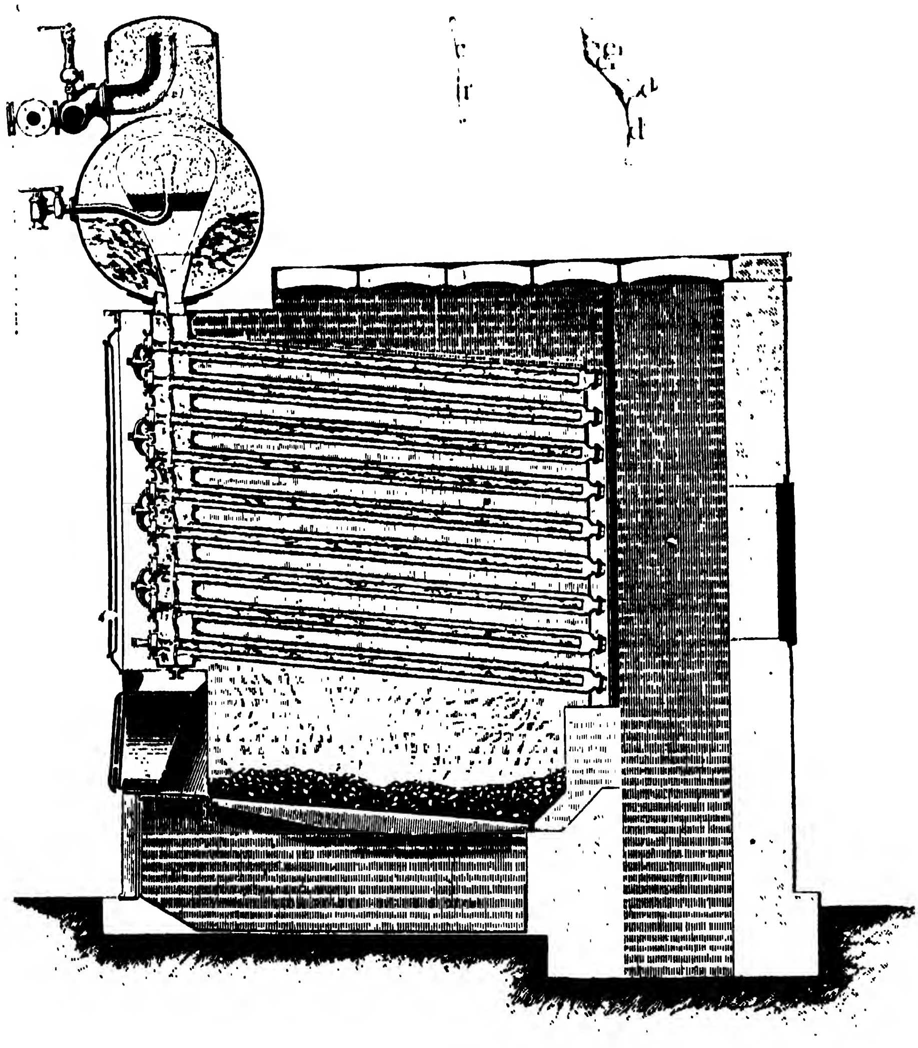


Fig. 18. Niclausse Boiler

There is danger also in allowing the water-level to become too high, as priming, that is carrying over of water with the steam, may ensue, with disastrous results to the cylinder covers of the engine.

If the feed water is of poor quality the boiler should be cleaned out weekly. In no case should it be cleaned less frequently than once a fortnight. In frosty weather, if the boiler is not in use, it should be run dry to prevent the water from freezing inside. Otherwise a small fire may be kept burning on the grate.

Above all, the care of the boiler should be in the hands of an experienced attendant, one who is competent and reliable, who realizes his responsibility and has the presence of mind necessary to meet any emergency that may suddenly arise. In the hands of

an inexperienced man a steam boiler is a danger of the most serious kind, involving probably the destruction of many lives and much property. In any case, under a careless man the repair bill will be greatly increased. The responsibility of the position of boiler attendant demands the closest attention to the duties, and a thorough appreciation of the dangers that may arise, and how they are to be met when the first symptoms appear.

PRODUCTS OF COAL COMBUSTION

When coal is burned on the grate various gases are evolved. The most important are: carbon dioxide, the development of which indicates complete and effective combustion, and carbon monoxide, the product of a less complete combustion.

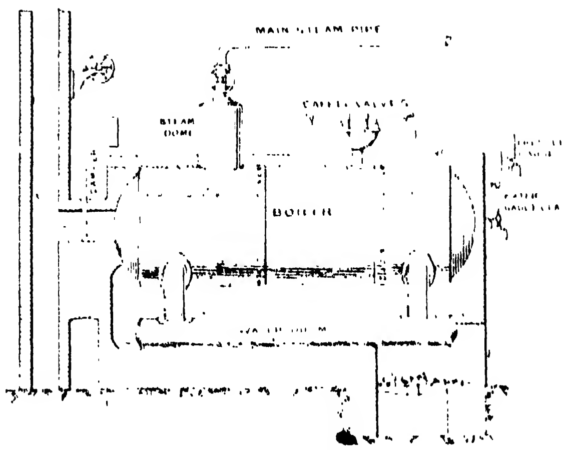


Fig. 10. Arrangement of Boiler with "Bouilleurs."

As already stated, these gases may be detected by their appearances. The carbon dioxide having a high temperature makes the particles of carbon luminous, and burns therefore with a large, visible flame. The carbon monoxide burns, on the other hand, with a low, blue flame.

A good stoker should endeavour then to produce a clear flame over the whole grate area and to avoid the appearance of black patches. These black spots indicate masses of coal wastefully distilling their hydrocarbons at a temperature insufficient for their combustion, and are due to a deficient supply of air at these places. To remedy the defect the clinker should be removed from the grate bars to ensure a free passage of the air, and the damper should be raised to increase the draught.

Smoke. Incomplete combustion or a premature cooling of the gases results in the formation of thick smoke and heavy deposits of soot. To avoid their production the temperature in the furnace and the supply of air should be kept sufficiently great by means of the damper.

When the fires have just been cleaned and coal is added, the temperature falls so considerably as to produce heavy fumes, unless an extra supply of warm air is supplied. To prevent the formation of smoke when stoking the furnaces two methods may be adopted. Of these the most efficient is called *coking*, that is, the coal as it is consumed is shoved back towards the end of the grate and new fuel is added at the front. The smoke evolved from the coal at the front end is consumed as it passes over the incandescent coal at the back together with the supply of air, which has had time to be heated to a temperature sufficient for combustion. The second method is simpler than the first, but may be used in conjunction with it. It consists in simply opening the furnace doors about an inch. The air which enters becomes heated to some extent by contact with the walls of the hot furnace, and on mixing with the smoke consumes it at the back of the grate.

Stoking. There are three methods of stoking in frequent use. The first consists in spreading the coal uniformly over the whole grate in layers sufficiently thin to prevent a serious fall of temperature. New coal should not be added before the previous charge has been thoroughly burned.

The second or coking method has already been referred to. The burnt coal is pushed from the front of the grate to the back end and a new supply added in its place. The gases as they are distilled pass back over the hot coals and are more completely consumed.

In the third method, which is called alternate firing, the charge is added to each side

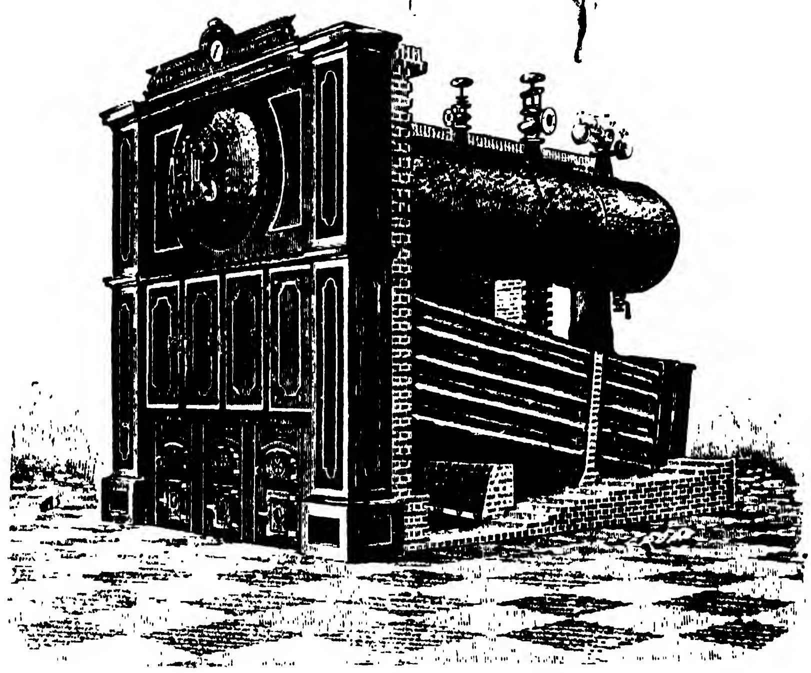


Fig. 20. Petry Dereux Boiler, with masonry removed

of the grate alternately. In this way the temperature is never seriously lowered, and there is always present some incandescent fuel.

Cleaning the Fire. The draught should be sufficient to keep the clinker in a soft pasty condition, in which state its removal is easy. Thin, deep grate bars give the best results, as the clinker does not so readily adhere, and tends to form in drops in the spaces, where it is easily loosened by means of an iron slice. Cleaning should not be undertaken at too frequent intervals. This, however, is not always possible; for example, when the clinker forms rapidly owing to bad proportions of the grate or to the use of very poor coal. In the former case the stoker can do very little to remedy the fault. In the latter case much may be done by picking from the coal the stones, and particularly the iron pyrites, mixed with it.

It must not be forgotten that too frequent or prolonged cleaning of the fire has serious consequences. If the furnace door be left open for a considerable time, the cold air which enters causes a fall of the steam pressure and a loss of efficiency, as the boiler plates become chilled. Further, the rapid variation of temperature has a disastrous effect upon the boiler structure itself, causing repeated contraction and expansion of the plates

with a consequent wearing of the seams and the necessity for frequent and costly repairs, besides the loss of valuable time. It is therefore of great importance that the stoker should be able to clean his fire rapidly and completely, so that the necessity for further cleaning may arise as seldom as possible.

STOPPAGES OF THE ENGINE AND BOILER

At certain intervals of the day, ordinarily at noon, the demand for steam may decrease owing to the stoppage of the engine. It is at such times, when a fall of pressure is allowable, that the stoker should dress his fire, feed the boiler, and do all the operations that tend to make the pressure fall. During the stoppage he will have sufficient time to recover the pressure while the demand remains small.

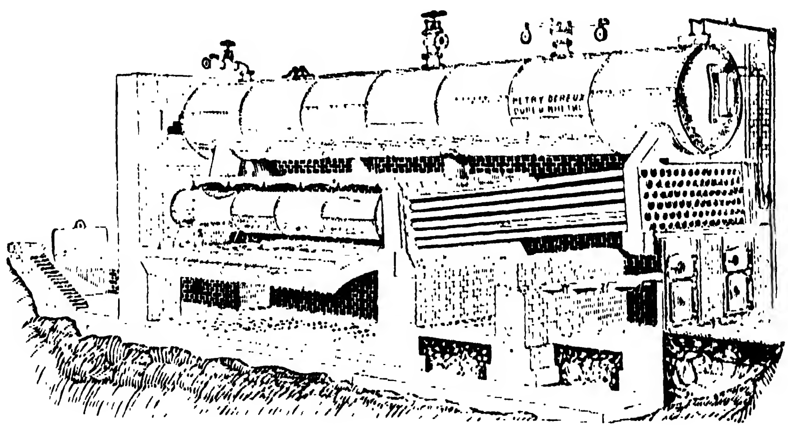


Fig. 21. Petry-Dereux Boiler, MacNicol type

At the end of the day's work, when finally stopping for the night, the grate should again be thoroughly cleaned, the fires banked with small coal, and the damper lowered to almost completely cut off the draught throughout the night. If the stoppage is to continue over the succeeding day the fire should be allowed to burn down until the pressure is not more than a few pounds, and then banked. In this way a considerable saving in coal is effected.

Feeding the Boiler. Although the feeding of the boiler is a simple matter, especially when done automatically, it is the most important of the stoker's duties, as any carelessness may result in disaster more serious than any bad handling of the fires could produce. Most of the terrible accidents that have carried desolation into many families have arisen from the misuse of the feed appliances. In the first place, the choice of the feed water and the means to be taken to prevent the formation of earthy and calcareous deposits will be considered, and thereafter the feed appliances themselves and the precautions to be taken to ensure their regular working will be dealt with.

Feed Water. The choice of feed water is of primary importance to the owner who considers his interests. Bad water wastes away the plates of a boiler to an extent that rain or chemically pure water would never do. When the water is evaporated the earthy and calcareous matters which it holds in suspension or partly in solution are

deposited upon the plates in the form of encrustations, or, as it is called, scale. Encrustations which adhere are the most objectionable. Whatever their appearance or composition they cause a continual wasting away of the boiler plates, and the growing thickness of the scale decreases the conductivity of the furnace walls, and thus seriously affects the evaporative power of the boiler. A very thin layer of matter suffices to reduce the evaporative power by from 10 to 15 per cent.

Generally the scale forms in the angles of the seams, and any small particle left after cleaning serves as a centre for new accretions. The foreign matter may be held by the water either in suspension or solution. In the former case, to remedy the defect, it is sufficient to store the water in reservoirs, where the impurities may be settled or filtered out. In the second case its removal is more difficult, as the substances in solution consist often of sulphates and carbonates of lime and alumina, or of magnesium or iron. The former are more dangerous, as they form crystalline and fibrous encrustations which adhere to the plates, while the latter form more amorphous and softer deposits. Acid waters cannot be used, as they quickly corrode the plates, and waters containing oils are equally dangerous. The grease which adheres to the rough surfaces of the plates transmits the heat very badly, and allows the metal to become overheated and burned. If this greasy water also contains a salt of lime the results are still more serious, as a lime soap is formed, which collects on the plates and reduces the evaporative capacity of the boiler to an extraordinary extent. As condenser water always contains a certain amount of oil it is not advisable to use such water for feeding the boiler.

PURIFICATION OF THE FEED WATER

There are offered for sale innumerable chemical compounds, which are claimed as certain remedies against the formation of scale, with its attendant evils and dangers. It must be remembered, however, that the nature of the water used must first be determined before any remedy can be applied with any certainty of success. Feed waters may be classified under four heads: 1st. Almost pure water containing impurities only in suspension. 2nd. Water containing carbonates of lime and magnesia. 3rd. Water containing both carbonates and sulphates. 4th. Water containing sulphates alone.

In the first case the impurities may be filtered or settled out; but if this is not sufficient the addition to the boiler water of small quantities of potato pulp, lichen, or similar vegetable materials will gather the impurities into lumps and prevent them from depositing as scale on the plates.

To deposit the carbonate of lime, tannin in the form of oak bark or the salt itself may be used. The addition of catechu, nutgalls, and other astringent materials containing tannic acid which decomposes the lime salts, may also be used with advantage. If both sulphate and carbonate of lime are present the tannin should be used in conjunction with soda. The only remedy for sulphate of lime is the use of caustic soda. Coating the internal surfaces of the boiler with a composition of gas tar retards the formation of hard deposits. The encrustations settle down in a loose earthy state and can be more easily removed.

It is also real economy to make the care of the boiler the sole duty of one man rather than to consider it as an additional charge. If the boiler is of low power, say 20 to 30 h.p., the stoker may act as engine attendant, but in large installations the engines and the boilers should be under the care of different attendants.

Boiler explosions, when they occur, are generally disastrous, and unfortunately their occurrence is too frequent. Occasionally when an ex[illegible] than usual takes place the public demand ne[illegible] and more stringent re[illegible] [illegible]ly effective safeguard consists in making an exhaustive enquiry to det[illegible] [illegible]uses, and in

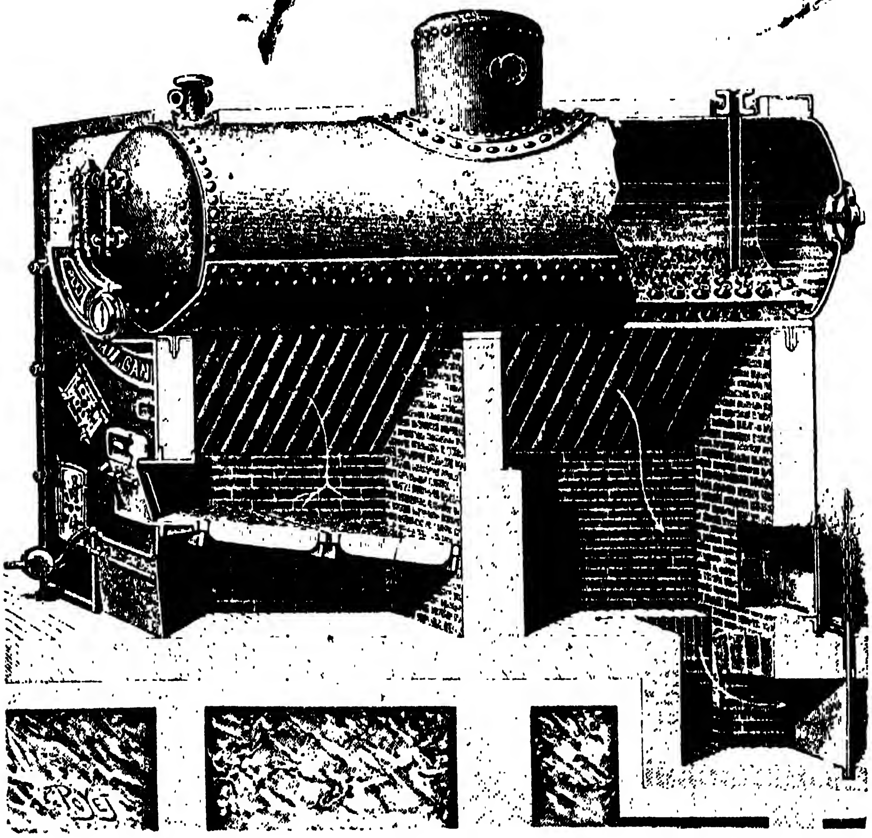


Fig. 38.—Side View of Turgan Boiler

taking precautions accordingly in future. Each accident forms the subject of an official enquiry, and the particulars are published, together with recommendations that may have been suggested as a result of the enquiry.

The following figures taken from official returns show the more frequent causes of accidents and their proportions:—

1. Defective design, construction, and arrangement, and defects in materials, ...	23 per cent.
2. Want of repair, defective repairs, bad usage, fatigue or thinness of plates, freezing of water in the pipes during stoppages, ...	28 „
3. Bad handling, lowness of water followed by injudicious feeding, excess of pressure, carelessness and negligence, ...	42 „
4. Causes unknown or incompletely determined, ...	7 „

It is always a difficult matter to determine the cause of an explosion, because the condition of the debris may easily lead to wrong conclusions, and more than one defect may have contributed to the accident. Notwithstanding these difficulties not more than 4 per cent of the accidents remain quite undetermined.

In order that [illegible] stoker may fully understand the nature of the defects, and the accidents th[illegible], the four classes already enumerated will be successively dealt [illegible]

Defect[illegible] In boilers having large flat surfaces explosions have resulted

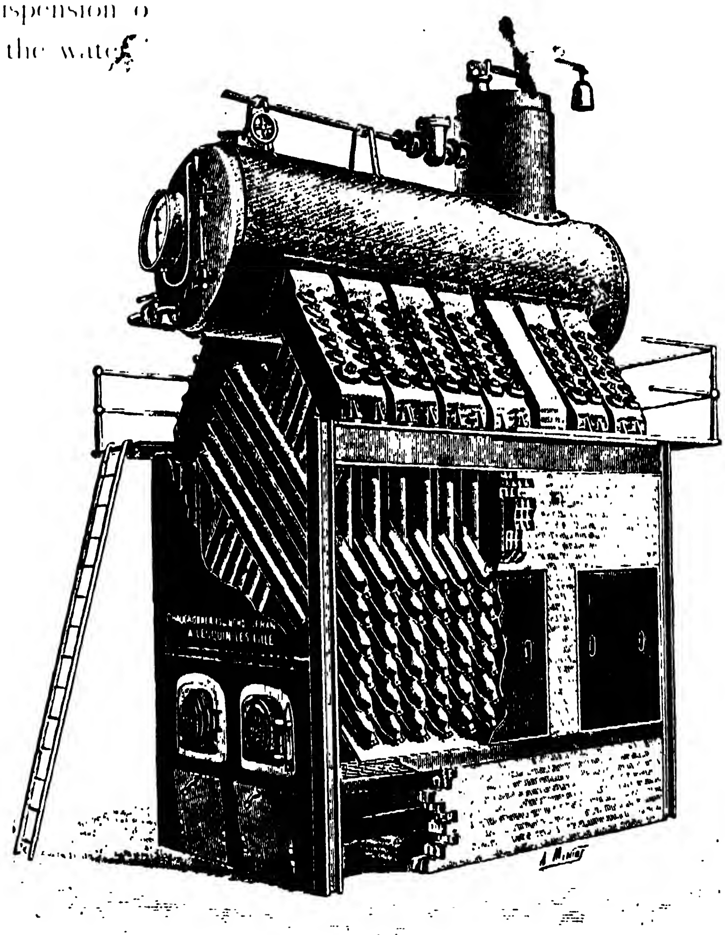


Fig. 39.—Crossed-Tube Borrot Boiler

from the fracture of the ties binding the surfaces together, when the ties are of insufficient section. Sometimes the riveted seams offer less resistance than the plates themselves. This may easily be avoided by good design. Internal parts, such as the furnaces, may not be sufficiently strong to resist the tendency to collapse under pressure, or the material may be of inferior quality, and lastly, the gauges may be so badly placed as to give unreliable indications.

Want of Repair.—Rapid deterioration takes place when the boiler is not kept continually in good order, when bad feed water is used, and when corrosion remains undetected. Numerous accidents occur through repairs being neglected or badly done, or through the need of repairs being overlooked. To detect weaknesses or leaking seams the boiler should occasionally be tested under hydraulic pressure.

Bad Treatment.—This, the most frequent source of trouble, which accounts for nearly half the accidents that occur, merits a more lengthy consideration. Often the

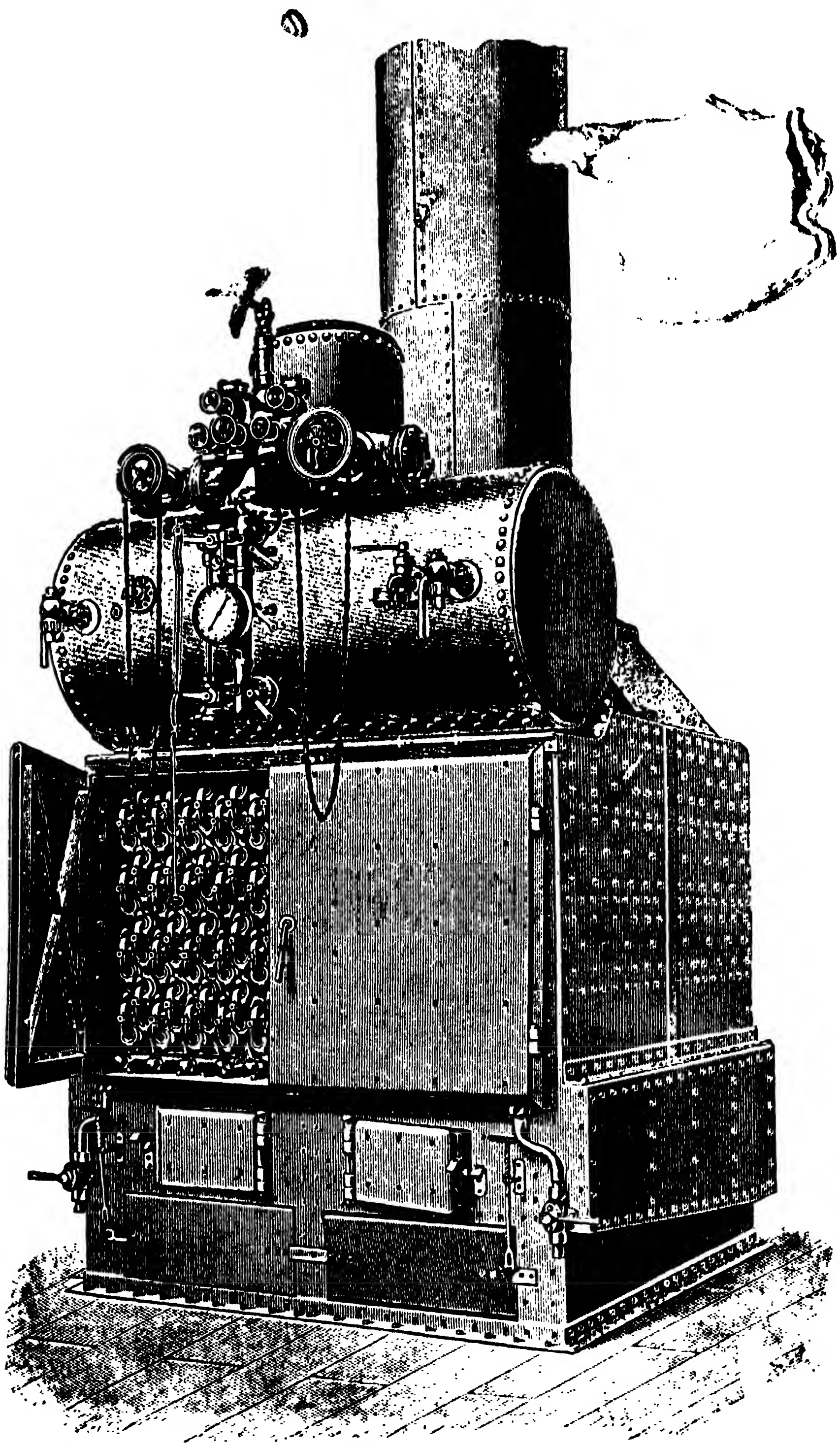


Fig. 40.—Niclausse Marine-Type Boiler

explosion is caused by the water-level falling below the normal, thereby uncovering the plates and allowing them to become red-hot. This may be due to several causes: the feed pipes may be obstructed, or they may contain air and fail to pass sufficient water, or they may leak, or in winter be frozen. When the water comes in contact with the

red hot furnace plates the evolution of steam is more sudden and rapid than the safety valves can deal with, the pressure rises enormously, and causes the hot plates in their weakened condition to suddenly collapse."

It is easy to say that the stoker should at once bank his fires the moment he notices such a state of affairs, but in practice it is not always possible to do so. The stoker may be ... his situation if he reduces the pressure and disorganizes the working ... Some engineers do not hesitate to say that a serious fall of the wa... always to the negligence of the stoker. Such an assertion

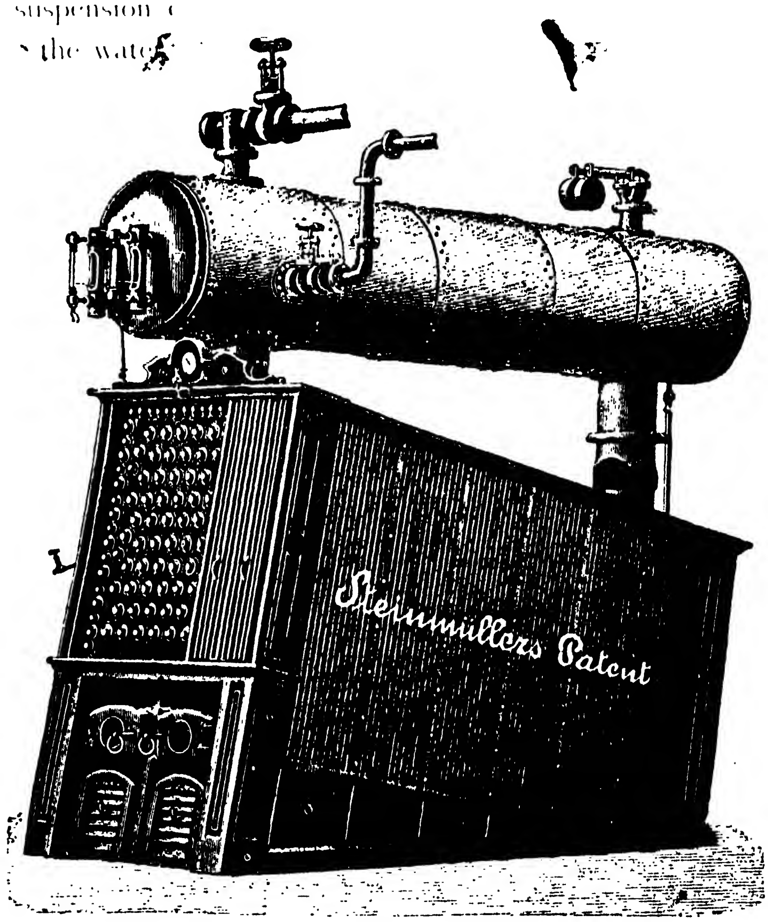


Fig. 41.—Steinmüller Boiler

is, however, both untrue and unjust, and is regrettable, as it has only the effect of making the stoker fear to reduce the strength of his fires to any considerable extent, or to bank them with earth, until the remedy is too late.

In the morning, when firing is commenced, a difficulty may present itself. The water may not appear in the gauge glass, although on the previous night, when stopping, the level may have been good. As already stated, the fall may be due to the decreased volume of the water when cold, and to the condensation of the steam mixed with the water. These causes are normal and well understood by stokers, but there are abnormal conditions which an ordinary man may know nothing of, and which even the experienced stoker may not appreciate or be able to prevent. The height of the water being unknown, the stoker, instead of stirring up his fire, should damp it still further, unless

he wishes to deserve dismissal. The only course to pursue is to bank the fires until the fault is detected and corrected. Accidents frequently result through inexperienced stokers failing to note the lowness of the water-level and proceeding as if nothing were wrong.

When the boiler has separate water legs, as in the elephant type, and these are not fitted with water indicators, the conditions may be particular[illegible] as the stoker has no means of knowing what is taking place in th[illegible]ally happens that the connections to these water limbs become obstructe[illegible] other reason

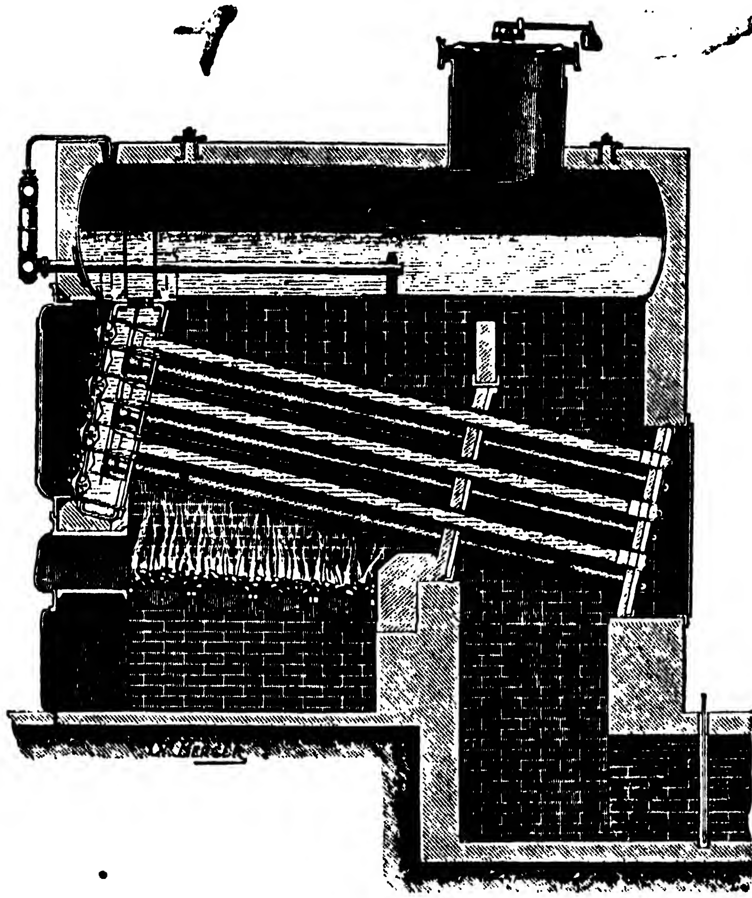


Fig. 42.--Joya Water-Tube Boiler

the limbs may become partially empty. As water is pumped into the boiler the level under these circumstances will take much longer to rise than it ordinarily would, having to make good the deficiency in the limbs. Meanwhile the furnace plates are possibly uncovered and are becoming red-hot, so that when the water ultimately reaches them a violent explosion results. To accuse the stoker of incompetence under these circumstances is unjust, for it is impossible for him to know that the limbs are empty, and that the water he is pumping in is not filling the boiler itself.

It must be admitted that in many establishments the boilers are too weak for their duty. This results from various causes. Apart from the boiler having been of too small capacity when first installed, the demands for steam may have increased, or the money set aside for repairs, which varies naturally with the power of the plant, may be

insufficient. There is a tendency on the part of owners to economize where boiler repairs are concerned, or to use cheap appliances that may not be wholly suitable. And in general an old steam generator is only replaced with reluctance by a more modern and powerful one, and only when the necessity becomes imperative. Rarely are the demands for steam regular—especially is this so when the steam is also used for heating purposes. The supply m[illegible] varied as required. Still more complicated is the case where the engine an[illegible], as in portable engines, because, owing to competition, the builders [illegible] to make the boiler just sufficient for the engine power.

Very f[illegible] are forced to an extent that can only have serious consequences, espe[illegible]e method adopted is the overloading of the safety valve

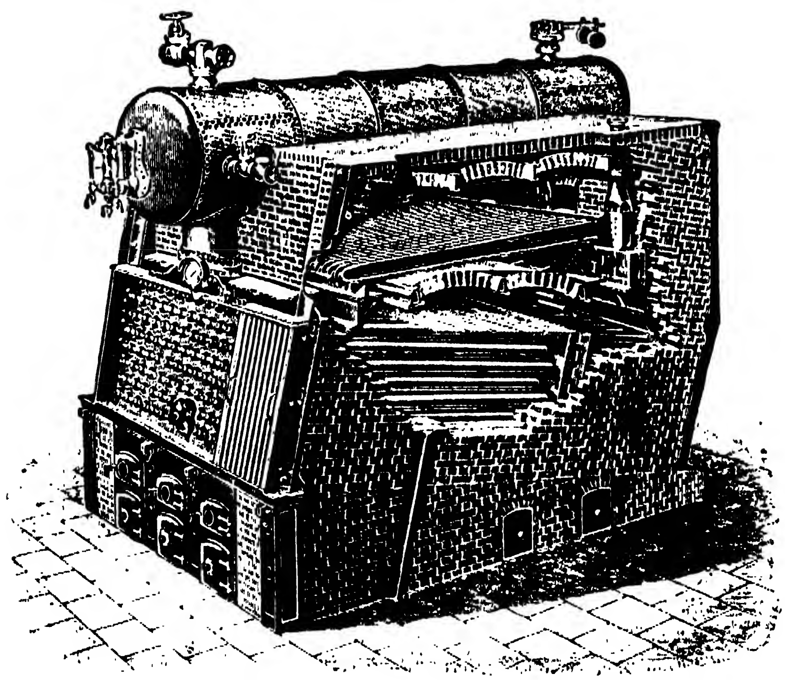


Fig. 43.—Steinmüller Boiler with Superheater

beyond all allowable limits. Other causes may lead to the rupture of the plates; for example, when the fires are being cleaned the cold air which rushes through the open furnace door may produce so sudden a cooling and consequent contraction of the plates as to crack them. Several serious boiler explosions have been traced to this cause. Rupture of the boiler plates results most frequently from the feed appliances being defective, or through failure of the non-return or clack valve to keep the feed water from escaping back, thus allowing the water-level in the boiler to fall until the furnace crowns are uncovered. If the plates become red-hot and are then submerged again an explosion is the inevitable result.

Enough has been said regarding water-level indicators, whether glass gauges or float alarms. All, without exception, are subject to errors, and their readings must not be accepted with too great confidence or without frequent checking and examination.

EXCESSIVE PRESSURE

Overloading the Safety Valve.—Interference with the safety valve in order to keep the pressure is a most dangerous practice. There is often considerable temp-

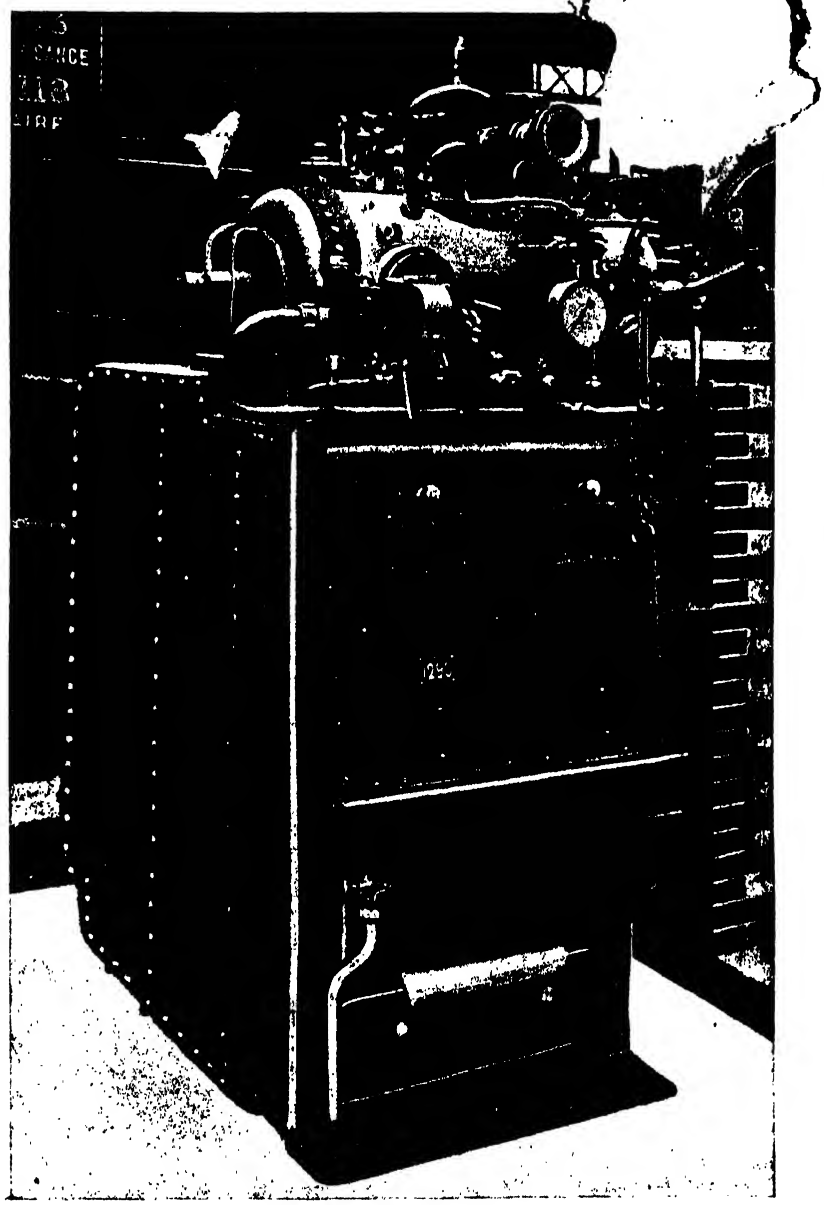


Fig. 44.—Niclausse Boiler, Portable Type

tation to do so, as the valve frequently is set to blow off before the regulation pressure is reached, and the stoker is further aware that his boiler has been tested hydraulically to twice the working pressure. It must be stated here that so high a testing pressure as is customarily used is not advisable. After a short time defects have been known to develop in consequence, through overstraining of parts that would otherwise have been perfectly safe and satisfactory if subjected to a less drastic test. A small definite

overload of the valve is an advantage. It should be set to blow off at a pressure a few pounds above the normal, to ensure a greater regularity of working.

Notwithstanding searching enquiry by the Board of Trade a proportion of the explosions that occur remain unexplained. Some of these accidents may be due to a phenomenon which is generally supposed to occur under certain conditions. If all the air has been p[illegible] boiled out of the water, and the fire is then lighted, the water, when perfectl[illegible] may reach a temperature much above the boiling point without the [illegible] team. It requires then only some slight disturbance—any outside sho[illegible] ae internal stress in the water, and cause it to flash into steam with a s[illegible] eat the boiler plates cannot resist.

In the next chapter the engines which utilize the steam generated by the boilers will be considered.

BABCOCK & WILCOX WATER-TUBE BOILER

The two models represent side and end sectional elevations of the boiler

Index to the Principal Parts

1. Upper or Steam Drum.
2. Feed-water Pipe.
3. Feed-water Non-return Valve.
4. Feed Pipe with Stop Valve.
5. Water-level Gauge.
6. Water Gauge Blow-off Pipe.
7. Pressure Gauge.
8. Safety Valve.
9. Main Steam Valve.
10. Steam Collecting Pipe.
11. Manhole.
12. Suspension Rods for Steam Drum 1.
13. Supporting Girders for Steam Drum 1.
14. Water Tubes.
15. Front Water Boxes.
16. Back Water Boxes.
17. Water-box Covers.
18. Tubes Connecting the two rows of Boxes 15 and 16 to the Steam Drum.
19. Mud-collecting Box.
20. Pipes Connecting the Back Water Boxes 16 to the Mud Box.
21. Cleaning-out Handhole in 19.
22. Blow-off Pipe for Mud Drum and Boiler.
23. Feed Inlet Baffle Plates.
24. Superheater Tubes.
25. Superheater Lower Chamber.
26. Superheater Upper Chamber.
27. Steam Connection between Boiler and Superheater.
28. Stop Valve of 27.

29, 30. Tubes Connecting the Steam Collecting Pipe 10 and the Superheater Lower Chamber.

31. Perforated Collecting Pipe for Wet Steam.
32. Blow-off Pipes from the Steam Drum 1 and the Superheater Lower Chamber.
33. Steam-blast Pipes for [illegible] from the Tube Surfa[illegible]
34. Doors through which S[illegible] Blast is applied.
35. Hot-gas Baffle Plates.
36. Supporting Plate for the Superheater Tubes.
37. Fire Bars.
38. Fire-bar Bearers.
39. Furnace Front Plate.
40. Furnace.
41. Fire Doors.
42. Ash-hole Doors.
43. Ash-hole.
44. Doors Giving Access to Front Water Boxes.
45. Brickwork.
46. Cleaning-out Doors.
47. Brickwork Tie Bars.

(*Model prepared from drawings kindly supplied by* Messrs. Babcock & Wilcox, Limited, Glasgow.)

Section II

THE STEAM ENGINE

THE STEAM ENGINE

Strictly speaking the term steam engine should be used to describe any machine which converts the energy of steam into useful work. In practice, however, the reciprocating engine is generally understood; the rotary engine and the steam turbine being essentially so very different in principle as to require separate classification. As a first classification, therefore, the following may be taken, viz., Reciprocating Engines, Rotary Engines, and Turbines.

The reciprocating engine consists of a cylinder in which the steam acts by pressure or expansion behind a piston. The motion of the piston is communicated to a crank on the main shaft, and the admission of the steam is controlled automatically by a distribution valve. When the steam acts only upon one face of the piston, the engine is said to be single-acting. When both piston faces are alternately acted on by the steam, the engine is called double-acting. In this case the motion of the piston is communicated from the piston rod to the connecting rod and thence to the crank, and the steam does work during each to-and-fro motion of the piston. In the single-acting engine work is only done during each alternate stroke, involving a considerable weight of engine for a definite horse power. On the other hand, apart from other advantages, the motion of the single-acting piston may be communicated directly to the crank through the connecting rods, thus reducing the moving parts and the weight. Until the introduction of forced lubrication, the single-acting type, having two or more cylinders and running at a high speed, was employed in preference to the double-acting type, with which such noiseless running could not be obtained.

Steam may act upon the piston in two ways—either in virtue of its pressure alone or by its expansive property. Generally the steam acts by pressure during the early part of the stroke and by expansion during the remainder. When the steam enters the cylinder throughout the whole stroke the pressure on the piston does not alter, and the working is said to be non-expansive. In the second case the working is expansive, and the pressure on the piston falls, after a certain point, as the piston moves forward.

The power developed by an engine is proportional to the steam volume of the cylinder, the mean steam pressure throughout the stroke, and the number of revolutions per unit of time. By increasing the revolutions alone the power of the engine would

be correspondingly increased, but the piston would move in the cylinder at a higher speed. In practice, owing to the weight of the moving parts, there is a limit to the speed of the piston, so that beyond this limit—[illegible],800 ft. per minute—an increase in the revolutions necessitates a decrease in the length of the stroke. On comparing a slow-revolution engine with a fast one developing equal power we find that the work done per stroke is less in the quick-revolution engine, so that much lighter moving parts may be used. The quicker the revolutions, therefore, the smaller becomes the size of the engine and the weights of the parts. An increase of steam pressure would for equal power permit of a decrease in the cylinder sizes, but the cylinder parts would require to be made sufficiently heavy and strong for the increased pressure.

When the steam is exhausted directly into the atmosphere the energy it still contains is wasted; and there is a still further loss due to the back pressure of the atmosphere, which amounts to from 14 to 15 lb. per square inch of the piston area. By condensing the exhaust steam instead of ejecting it to the atmosphere the back pressure may be reduced to nearly 1 lb., which means an increase of the effective steam pressure by about 13 lb. Engines may be therefore condensing or non-condensing according as a condenser and the necessary pumps are fitted or not. The addition of a condenser involves a considerable quantity of expensive gear, which may more than outbalance the saving when the power of the engine is below a certain amount, and cooling water is expensive.

From what has been said above it will be obvious that the design of an engine must be determined by the conditions under which it is to work. For pumping engines, where the size need not be curtailed, and steady, continuous running is essential, a slow-moving engine of the simplest construction is desirable. Where, however, space is valuable, the size must be reduced and the speed increased. In electrical power stations the speed of the engine is made sufficiently great to permit of its being directly coupled to the dynamo.

Non-expansion Engines.—During the whole of the working stroke steam is admitted behind the piston and exhausted throughout the return stroke while still at a high temperature, and therefore still capable of giving up a great amount of energy. All this energy is lost, so that the efficiency of non-expansive engines can never be high enough to warrant their use.

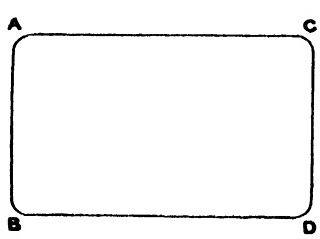


Fig. 45

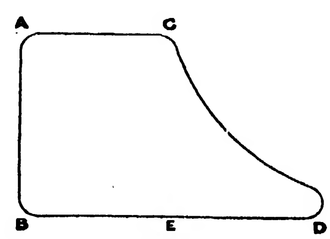


Fig. 46

Expansive Engines.—In expansive-working engines steam is admitted behind the piston until it has reached a certain predetermined point, when the admission is cut off by the main valve or by a separate variable expansion valve working in conjunction with it. The steam in the cylinder then expands behind the piston, doing useful work that would otherwise be lost, and thus a great reduction in the steam consumption is effected. To make the difference between the two methods of working clearer, the diagrams figs. 45 and 46 have been drawn from purely ideal considerations.

In fig. 45 the rectangle ABDC represents the quantity of steam used per stroke when the steam acts by simple pressure only, or it may represent the work done in the cylinder. If the steam is admitted, say, during the first half of the stroke, and is then allowed to expand until the end, the diagram of the work done will be as shown in fig. 46. The quantity of steam represented by the area ABEC is now only one-half, while the work, represented by the area ABDC, is equal to nearly three-quarters of the work developed when working non-expansively and using a full cylinder of steam. There is therefore great economy in expansive working, although the power obtainable from a definite engine is actually less than it would be if working non-expansively. By retarding the point of cut-off the engine may be made to develop a greater power, though less economically so far as steam consumption is concerned. It is often very advantageous to be able to work the engine under an overload for a short time, the loss of economy being of secondary importance under the circumstances.

When the initial pressure—and therefore temperature—of the steam is not great the expansion may take place in one cylinder, as the fall of temperature will not be so excessive as to cause great cooling of the cylinder walls and consequent condensation of the live steam. If, however, the initial pressure is great, especially with such pressures as 160 to 180 lb. per square inch, the expansion should be spread over two or more cylinders or sets of cylinders, according to the power, so as not to produce in any one stage too great a range of temperature. When the expansion takes place in two stages the engine is said to be compound, and when in three stages, triple. With present-day pressures quadruple expansion is seldom used, except for marine purposes, as the gain is not sufficiently marked to warrant the more expensive construction of the engine.

Distribution Valves.—The proper distribution of the steam supply to the cylinder is effected either by one simple valve or by separate valves for the admission and the release of the steam. By means of the distribution valves steam is admitted up to a certain point of the stroke, then cut off and allowed to expand, and finally is transferred to the succeeding cylinder or allowed to exhaust. In the case of the single D-slide valve, which is more generally used than any other type, the steam supply to both sides of the piston is regulated by it. When separate valves are used they are operated in a definite order by a suitable gear. Several of the types of distribution valves most generally used will be considered in the following order:—

1. The D-slide Valve.
2. Superposed Valves of the D type.
3. Piston Valves.
4. Rocking Valves and Drop Valves.

1. In the early double-acting pumping engines, which merely raised and lowered pump rods, Cornish equilibrium valves were used, and controlled from the pump rod by tappets. Later, when engines were made to rotate a shaft, Murdoch, Watt's manager, introduced the long D-slide valve running from the port at one end of the cylinder to the port at the other, in conjunction with an eccentric on the shaft. At a still later date

the valve was shortened to the form now so generally used. Fig. 47 shows the valve in its chest. It consists of a D-shaped shell sliding upon a machined face at the side of the cylinder, so arranged as to open communication between the cylinder ports and the steam supply or exhaust.

The valve is held freely in a frame on the end of the eccentric rod, so that the

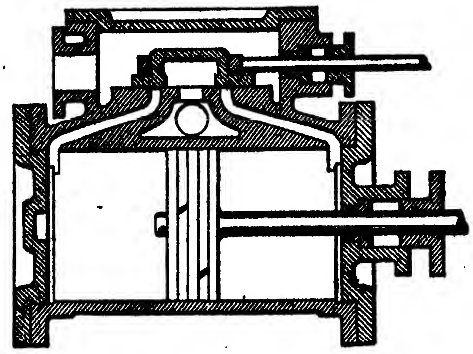


Fig. 47.—Arrangement of Cylinder and Valve Chest

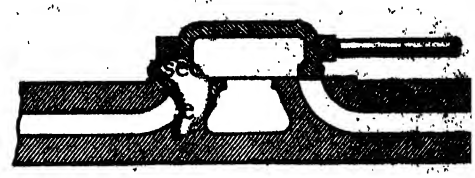


Fig. 48

steam pressure may force the working faces tightly together to prevent the leakage of steam, and the to-and-fro motion is generally controlled by an eccentric on the shaft. If the faces of the valve were just sufficient to cover the ports (as shown in fig. 48), steam would be admitted or released throughout the whole stroke of the valve or piston. To permit of expansive working the valve faces are extended both externally and internally, so as to admit steam during only a portion of a stroke and to give compression and release. These extensions are called respectively *outside* and *inside laps.* Steam will not be admitted to either end of the cylinder until the valve has been displaced past its mid position by the amount of the outside lap, and the admission is cut off before the valve reaches the mid position by the same amount. The inside lap affects the steam release in a similar way. Live steam, however, should just be entering the cylinder when the piston is at the end of the stroke. To effect this the eccentric is advanced sufficiently beyond the right angle, which it otherwise would make, with the crank position. In practice it is advisable to admit steam before the piston is quite at the end, so as to cushion it and assist in changing the direction of its motion; the eccentric is accordingly advanced by a still further amount called the *lead.* The amount by which the angle between the eccentric and the crank exceeds a right angle is termed the *angular advance.*

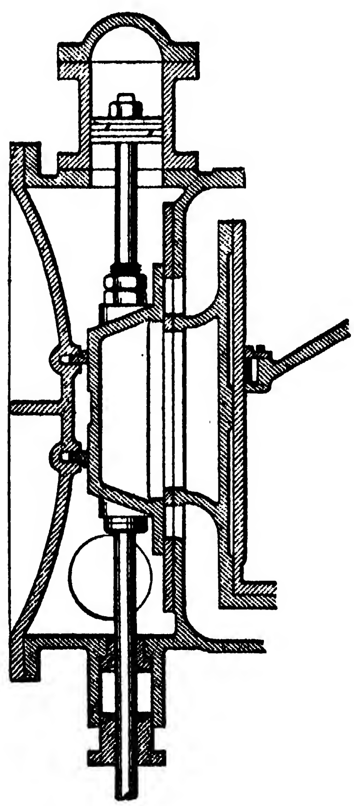


Fig. 49.—Slide Valve with Balance Piston and Relief Frame

By increasing the outside lap the ratio of the steam expansion may within limits be made as great as desired. The valve faces are made frequently of about twice the area of the steam ports. When the valve is of any considerable size the steam pressure on the back of the slider, forcing it against the working face, involves a serious loss of

power necessary to overcome the friction. It is customary in large engines to use relief frames at the back of the slide to keep the steam pressure from acting there (fig. 49). By reducing the necessary travel of the valve the loss can still further be reduced. This is done by making the valve double-ported, as shown in fig. 50. In this way the area of steam-port opening is doubled for a given travel of the valve. A similar arrangement is the well-known Trick valve, which has a steam passage running through it, as shown in fig. 51. When it is necessary to reduce the travel of the valve still further the number of ports may be increased, as in the gridiron valve, which may have ten or more port

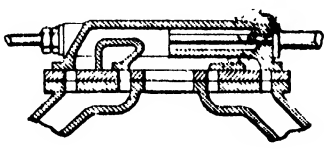


Fig. 50. Double ported Valve

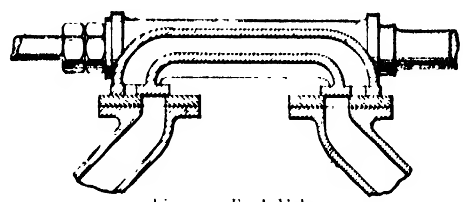


Fig. 51. Trick Valve

openings. Fig. 49 shows a balance piston as used in conjunction with large and heavy vertically-placed valves to support their weight. It is not customary to fit the simple **D**-slide valve to the high pressure or intermediate cylinders of large engines on account of the large surfaces which are exposed to the high pressure. They are generally used for the low-pressure cylinder only. In one respect the simple valve excels all others, in that it acts as a relief valve under an emergency. If water collects in the low pressure cylinder it may find an exit to the condenser by forcing the valve slightly off its facing, whereas with other forms, such as the piston valve, no rapid escape is possible, and damage may in consequence be the result.

2. **Superposed Valves.** — When the simple **D** valve alone is used it is not practicable to cut off the steam admission to the cylinder much earlier than half stroke, because the period during which compression takes place is determined by the duration of the expansion. To commence closing the exhaust earlier than mid stroke would give excessive compression. When an early cut off is required it is customary to add an expansion valve to control the steam supply before it reaches the slide valve, which distributes the steam to the ends of the cylinder.

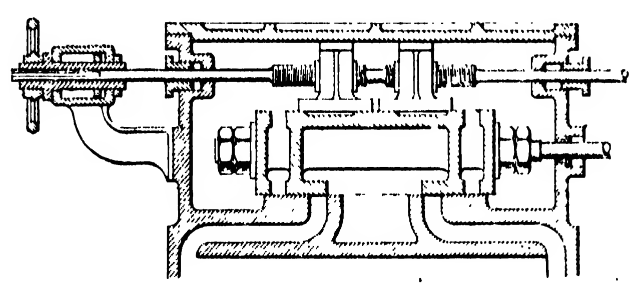


Fig. 52. Meyer's Hand controlled Expansion Valve

Meyer's expansion valve, shown in fig. 52, belongs to this type, but it has the additional advantage that the point of cut-off, and therefore the expansion, can be varied at will while the engine is running. The top slide, instead of being in one piece, is made in two separate parts, carried on a rod cut with a right- and a left handed screw. An eccentric moves the expansion valve over the ports in the face of the distribution valve as before, while the separation of the two parts, which determines the point at which the steam is cut off, can be altered by turning the screwed spindle by means of the hand wheel.

In 1834 Farcot introduced another form of expansion valve designed to cut off the steam more rapidly than can be done with the ordinary valve when displaced by an eccentric, and thus to obviate the loss of steam pressure which occurs as the ports are slowly closed. The arrangement, as before, makes use of two valves, one working on the back face of the other. The distribution valve is worked by an eccentric, while the other on the back of it is controlled by a vertical shaft and a cam. Springs press the expansion-valve portion against the lower valve, so that it is carried by friction with it as it moves, until the two separate parts of which the expansion valve is composed are stopped by butting against stops on the cam.

Howe's link gear, commonly known as the Stephenson gear, may be described here, as it also permits of the expansion being varied as desired, besides enabling the engine to be reversed. As shown in fig. 53, two eccentrics, one for forward and one for backward running, are keyed to the shaft in a definite relationship to the crank, the forward eccentric being in advance and the backward eccentric being behind by the same angular amount. The ends of the eccentric rods are coupled to a slotted arc or link, which engages freely with the end of the valve rod. The link is suspended from a pendulum rod attached to a hand lever, by means of which it can be raised or lowered. When the link is raised the forward eccentric rod is brought directly in line with the valve rod, so that the valve motion is determined solely by this eccentric. Similarly, when the link is lowered until the backward eccentric rod is in line with the valve rod, the valve is displaced, reversing the steam distribution, and the backward eccentric controls the motion. By placing the link in an intermediate position the difference of the two eccentric motions determines the motion of the valve. It is the same as if the throw of a single eccentric were reduced, and thus the point of cut-off is advanced, giving a greater expansion and compression. When the link is put in mid position the two eccentrics balance one another and the valve remains practically stationary. With link gears of this and other types it is therefore possible not only to reverse the motion of the engine, but also to vary the ratio of expansion to suit the load on the engine. The middle of the link is generally called the dead point or mid link. In practice, however, the dead point, at which the valve is hardly displaced, is some distance from the centre point of the link.

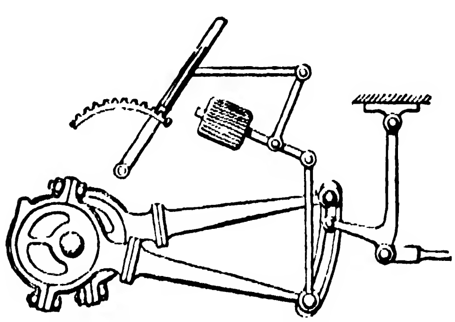


Fig. 53.—The Howe or Stephenson Link Gear

3. **Piston Valves.**—Slide valves of the **D** type cannot be used in large high-pressure engines, as the power required to move such great heavy valves to and fro against the frictional resistance is a quite considerable percentage of the total power developed. Piston valves similar to that shown in fig. 54 are used almost always on the high-pressure cylinder of marine engines and very frequently on the intermediate cylinders. The valve consists of two pistons on one spindle, working in a cylinder, and so arranged as to cover and uncover rings of port holes cut around the cylinder walls. The pistons are kept steam-tight by means of piston rings. So far as the

steam pressure is concerned the pistons are balanced. The engine has therefore to overcome only the resistance due to the friction of the piston rings and the weight of the valve, which is very small compared with that of the slide-valve type.

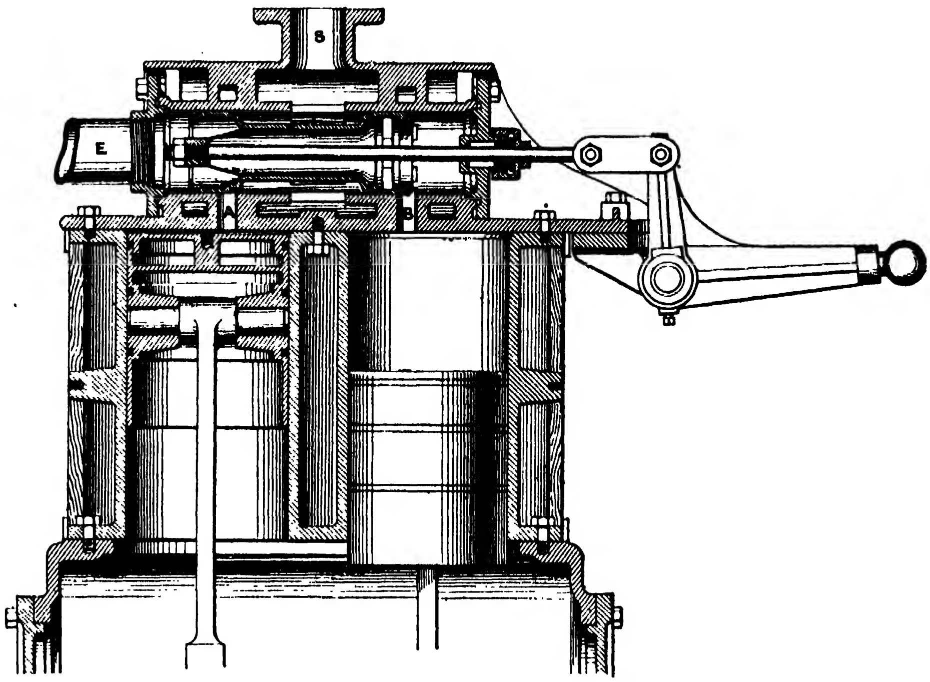


Fig. 54.—Section of Westinghouse Engine showing Arrangement of Piston Valve

4. **Rocking Valves and Drop Valves.** -There is one serious objection common to all valves which control both the steam admission and the exhaust. The high-temperature steam is brought into close contact with the low-temperature exhaust at each stroke, involving a very considerable loss of economy due to the condensation of live steam which takes place. It is also very difficult to design such valves with small steam clearance spaces. The steam contained in the passages is almost wholly lost when exhaust takes place; and further, in large engines it is more difficult to govern the engine, as after steam is cut off by the governor the clearance volume of steam continues to act. In moderate-speed engines, and where great economy is desired, it is customary, therefore, to use four separate valves to control the admissions and exhausts from the two ends of the cylinder, thus separating more completely the live- and exhaust-steam passages. In the Corliss gear, which will be described more fully later, rocking valves of the form shown in figs. 55 and 56 are used. Valves of this kind can be placed very close to the cylinder, so as to give the smallest possible amount of waste clearance space. The four valves are driven through connecting rods from a common wrist plate or eccentric. In the case of the exhaust valves the drive is positive, that is, the valves are both opened and closed by the eccentric. The admission valves, on the other hand, are provided with spring connections to the eccentric rods, which release the valves as soon as the points of cut-off are reached

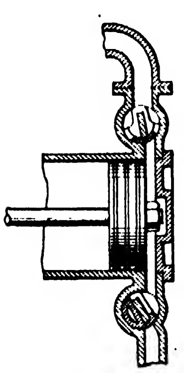


Fig. 55

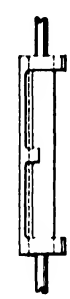


Fig. 56

and allow them to close sharply under the action of strong springs. In this way the loss of pressure due to wire-drawing of the steam, as the ports are gradually closed, is avoided. The Corliss rocking valve suffers from the defect that it is difficult to lubricate and requires considerable power to move it, especially when the pressure of the steam is high. Besides this it is not balanced, which means that a wide range of adjustment is required in the dash pot, and it is difficult to keep steam-tight over the working face. It has, on the other hand, the advantage of very smooth running without shock or excessive wear. Cornish or mushroom valves are used, as in the Sulzer engine, in preference to the rocking valve. From fig. 57, which shows the type, it will be seen that the valve is balanced and frictionless, making it very light to work. An objection to their use is the severe shock that occurs as the valve drops back upon the seating, thus tending to limit the speed at which the engine can with safety be run. As the valve has two faces, which must both be steam-tight, it will be obvious that trouble may be experienced when the valve heats and expands, especially when superheated steam is used. The separation of the faces will increase, so that one of them is bound to allow steam to leak through. It is a common practice to grind the valves on to their seatings when hot. To overcome this objection the valve is sometimes built up in two pieces, held springily together, but complications of this nature very often introduce other equally serious troubles.

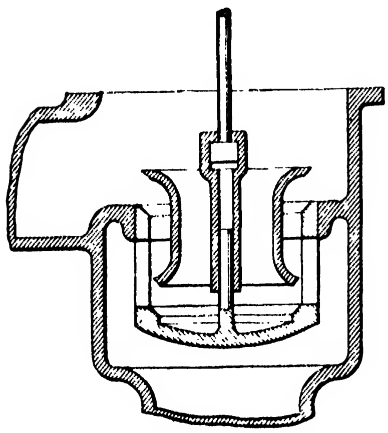


Fig. 57.—Cornish or Mushroom Valve

Morley's piston drop valve, introduced with very considerable success by Cole, Marchant, & Morley, Limited, has none of the objections of the Corliss or mushroom valves. It consists of a piston (fig. 58) working in a small cylindrical liner, through the sides of which the steam ports are cut. The valve is balanced, is easy to move, and when released by the trip gear there is no shock upon the valve itself. These features permit of the engine being run at an unusually high speed. It is further claimed that steam superheated to even 700° F. can be employed* without any of the ill effects experienced with ordinary valves.

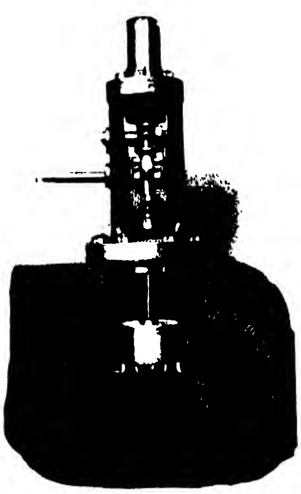
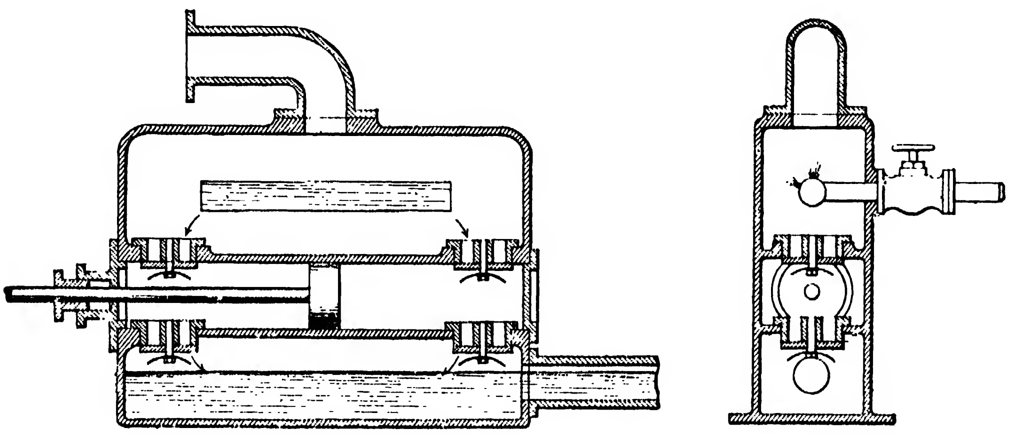


Fig. 58 Morley's Piston Drop Valve

Condensers. When it is required to obtain the greatest possible power from an engine, and to work economically, and where the supply of fresh feed water for the boilers is limited, it is necessary to reduce the back pressure on the exhaust side of the piston by means of a condenser, which liquefies the steam and produces a more or less complete vacuum, and to return the condensed steam to the boiler. Two general types of condensers are employed to obtain certain of these results, namely, (1) jet condensers and (2) surface condensers.

A third type, the ejector condenser, is sometimes also used when a supply of cold water flowing under a considerable head is available.

In the jet condenser the exhaust steam and the cold condensing water are brought into intimate contact, which is undoubtedly the most effective method of liquefying the steam. On the other hand, the pump requires not only to remove the condensed steam and water vapour, but also the water used for condensing it. In fig. 59 an arrangement is shown in which all the parts are contained in one casing. The exhaust steam enters at the top and comes into contact with a spray of cold water drawn from an external tank. A pump is supplied to draw away the condensed steam, vapour, and air, and also the injected condensing water. This pump must be of ample size to remove all the water vapour if a satisfactory vacuum is to be obtained. The pump delivers into a hot well, from which the boiler feed pumps draw their



Side Sectional Elevation

End Elevation

Fig. 59.—Jet Condenser and Pump

supply. It is essential, if the boilers are to be fed from this hot well, that the condensing water should be sufficiently pure for the purpose, and that the steam should be free from grease, otherwise deterioration of the boiler will more than counterbalance the saving from the use of the condenser. Jet condensers are essentially of simple design, having, unlike the surface condenser, but few joints that are likely to leak and admit air. They are frequently used in conjunction with stationary land engines, where the supply of fresh water is ample and not costly. If the condensing water, which amounts roughly to about thirty times the weight of steam to be dealt with, has to be bought at any considerable price, there is no advantage gained by the use of a condenser. It is less costly under such circumstances to use the exhaust steam directly in feed-water heaters, or for other purposes, without attempting to reduce the back pressure on the piston.

Surface Condensers.—When the condensing water is not of sufficiently good quality for boiler feed it must be kept separate from the condensed steam. For this purpose the surface condenser shown in fig. 60 is used. It consists of nests of small brass tubes of about $\frac{7}{8}$ in. external diameter, through which the cold and not necessarily pure condensing water is pumped, and around which the steam passes. For this purpose a separate circulating pump is required. The exhaust steam condenses

in contact with the cold tubes and falls to the bottom of the casing, from whence it is drawn by the air pump and sent to the boiler-feed supply tanks. Only the actual condensed steam and vapour require in this case to be dealt with by the air pump. It is customary, however, on account of the presence, through leakage, of air, which must be removed, to make the air-pump capacity as great as that required for a jet condenser. In certain cases the surface condenser is arranged to be used, when desired,

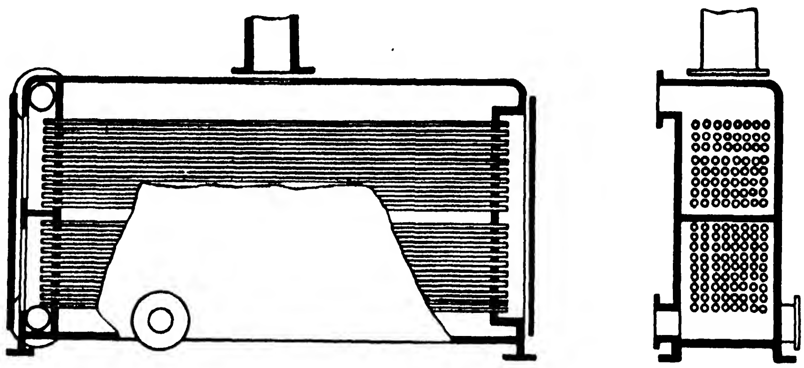


Fig. 60.—Surface Condenser

as a jet condenser. The presence of air in the condenser is objectionable, not only on account of the effect it has upon the vacuum, but also because the condensation of the steam appears to be retarded by the presence of even a small quantity of air. From the figure it will be seen that the tubes are divided into two groups. The cold feed water is pumped by a separate circulating pump in through the lower group and away through the upper. The steam passes in the reverse direction, that is, from the top downwards, meeting the coldest water at the bottom. On account of the severe expansions and contractions which take place in the condenser considerable trouble is experienced in keeping tight the junction of the tubes in the end plates, and as the condensing water is generally quite unsuitable for the boiler, as, for example, in marine work, where salt water is used, such leakage is very objectionable. Two methods of connecting the tube ends to the end plates are shown in fig. 61, and of these the ferule method is the more satisfactory.

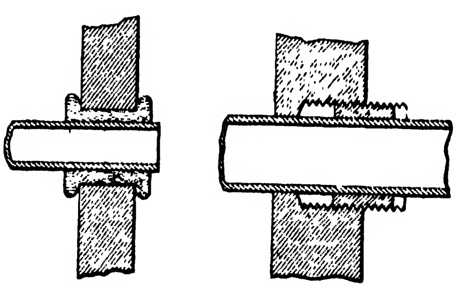


Fig. 61.—Condenser Tube Connections

The tubes are made of brass tinned externally to prevent the corrosion which is produced by the deposits of grease from the steam. Sometimes also they are tinned internally when the condensing water has a corrosive effect. Copper tubes are never used, as they quickly deteriorate. A surface condenser should have a tubular surface about twenty times that of the grate area of the boilers supplying the steam, and about double their heating surface.

TYPICAL STEAM ENGINES

The varied requirements of steam users have led to the construction of innumerable designs of engines, each specially suited for use under certain circumstances. To attempt any description of other than the most typical of these is quite impossible in the space here available. All that can be attempted is to give brief descriptions of the chief types which involve the principles underlying the design of the majority of the steam engines in general use. It is very difficult to make a classification sufficiently comprehensive and yet clear enough for descriptive purposes. At the present time engines are very generally designed to use steam at a high pressure, whether single- or double-acting. For many purposes high-speed engines are preferable to those of low or moderate speeds, and are very extensively used, especially for the driving of dynamos, fans, and similar plant, and where space is limited. On the other hand, the superior steam economy of moderate-speed engines, and their suitability for certain services, offer advantages that cannot be overlooked. Both classes—high-speed and moderate-speed—have their respective merits. In the pages which follow, descriptions will be given of the more typical of each kind.

No classification into condensing and non-condensing will be attempted, as any engine may be designed for use with or without a condenser as required.

Beam Engines.—Mention of the beam engine is made solely on account of its historical interest. At the present day it has been almost entirely supplanted by the direct-acting engine. Many of these engines are still, however, to be seen driving mills, though such examples are becoming increasingly scarce. In mining districts their use is more general, as the beam engine offers certain advantages where the direct raising and lowering of pump rods is concerned, and coal consumption is not of serious moment. In general, however, the great space occupied, the weight of the engine, and the heavy foundations and buildings required to house it, make their employment impracticable. The chief detail of interest is the parallel link gear used between the piston-rod head, which moves in a straight line, and the beam end, which moves in an arc. The link gear was used in preference to guides, which, in the early days of engine building, were more difficult to manufacture.

Horizontal and Vertical Engines.—By connecting the piston head directly to the crank, through the intermediary of a connecting rod, the necessity of a beam was dispensed with and the size of the engine greatly reduced. It is possible also, on account of the direct connection and the lighter moving parts, to make the engine work at a higher speed, with a consequent reduction in the size of the necessary foundation and the engine house. Engines are made either horizontal or vertical or diagonal, to suit the conditions under which they are to work; questions regarding space and cost being generally the determining factors. Horizontal engines take up little head room compared with vertical engines, but require more floor space, which, in certain circumstances, is of importance. A great advantage is the small amount of metal required between the various parts of the engine, as one bed plate carries the cylinder and main bearings without involving the

use of columns, as in the vertical engine. Unless in the smallest sizes, where the weights of the parts are not great, trouble is experienced through unequal wearing of the cylinder liner, packing rings, and rods. The weights act downwards, so that the wear is always

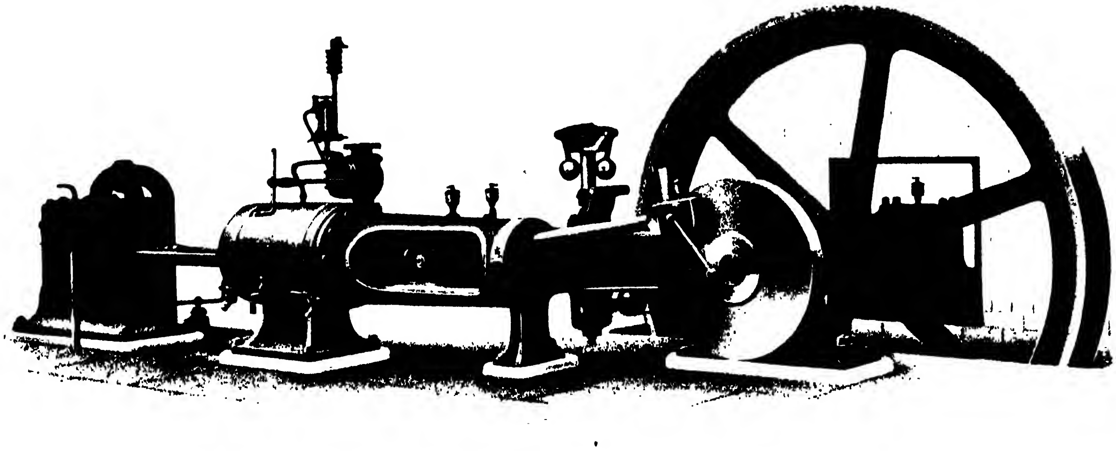


Fig. 62.—Robey Horizontal Engine with Jet Condenser

on one side of the cylinder. In the larger engines, to remedy this defect it is customary to prolong the piston rod through a gland in the back cover of the cylinder, and, if necessary, to support its end on a guide. The projecting tail rod is often utilized to work the air pump levers if the engine is condensing. There is no remedy for the tendency of the rods to wear oval, and too many supports may give more trouble than relief through the parts working out of alignment, especially when the bed plate is very long and the foundation not sufficiently rigid. Fig. 62 shows a horizontal engine with the tail rod extended to work a jet condenser. Vertical engines may have their cylinders either at the bottom or at the top, in which latter case the engine is said to be of the inverted type. In general, for a definite speed and power, the vertical engine is more costly than the horizontal type. Besides the bed plate, which is still necessary to carry the main shaft, the cylinders require to be supported on heavy columns sufficiently strong and rigid to stand the thrusts of the parts, but there is no tendency to unequal wearing around the cylinder and glands, as the weights act vertically along the rods. Fig. 63 shows a very old type of vertical engine with the cylinder at the bottom and the shaft and flywheel at the top. The heaviest moving parts are thus in

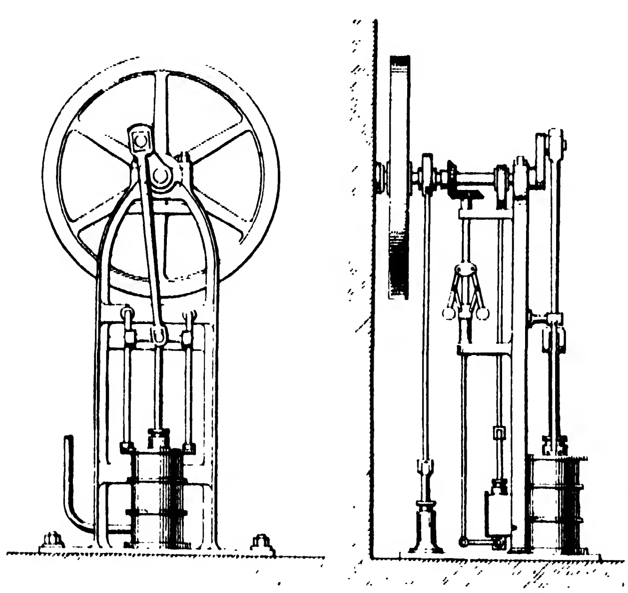


Fig. 63

the worst position for steady running and require heavy columns for their support. It is generally more convenient to have the shaft low down and the cylinders on top, as, for example, in marine engines. An illustration of a marine engine is given in

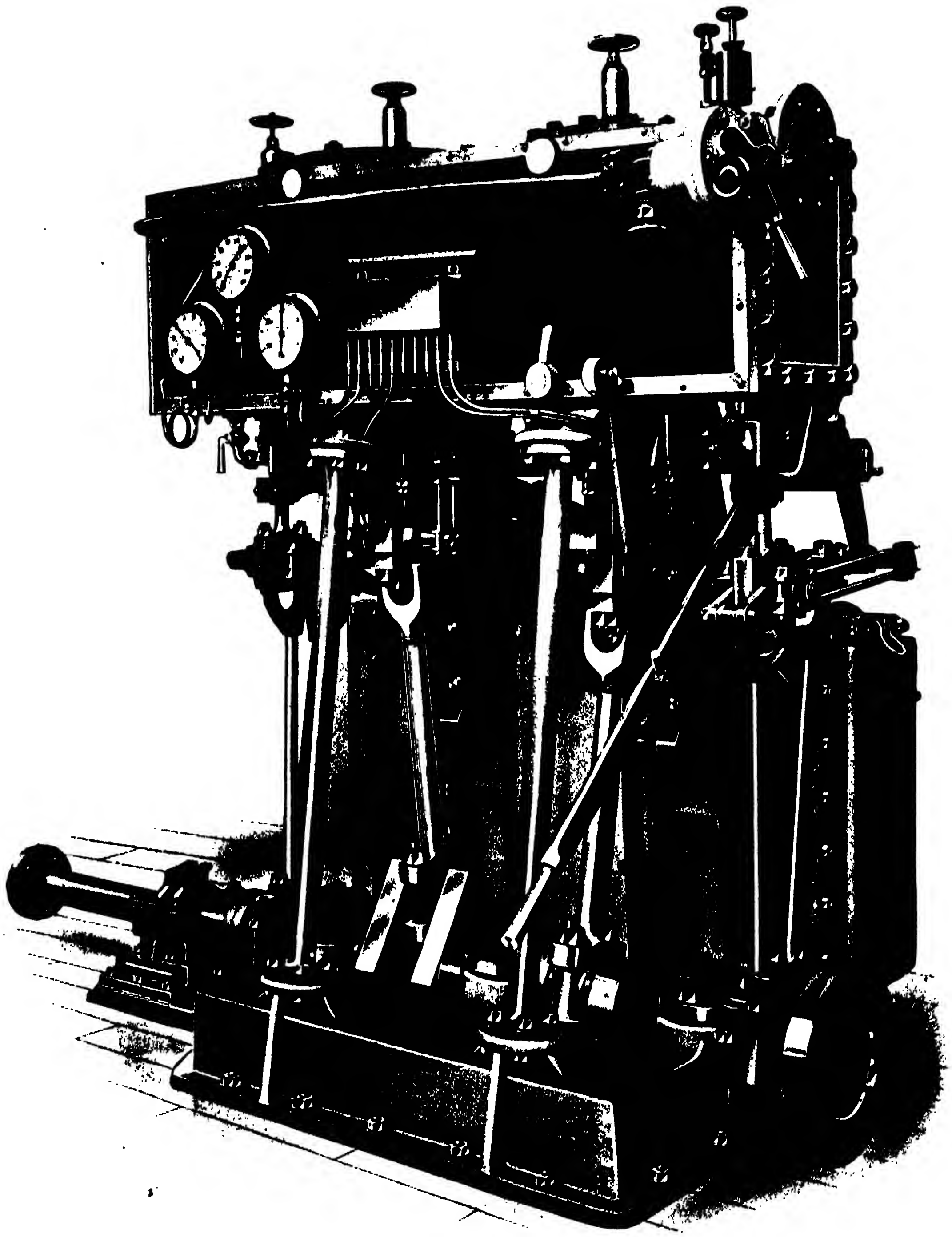


Fig. 64.—Marine-Type Engine with Surface Condenser

fig. 64. It will be noted that the columns have been utilized to form the condenser casing. In fig. 65 a typical small stationary engine, with all the parts self-contained, is shown. Under certain circumstances a compromise has to be made between the horizontal and vertical types. Light-draught paddle steamers, for example, in which

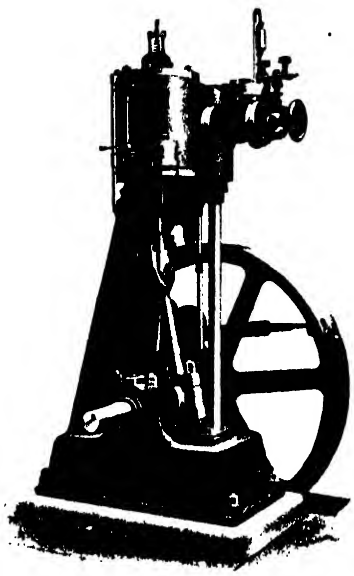


Fig. 65.—Tangye Single "Archer" Engine

both the floor space and head room are limited, are frequently fitted with the diagonal type of engines shown in fig. 66. In this way a sufficiently long stroke and connecting rod are obtained. Wall engines are often used where floor space is very valuable and where the nature of the drive permits. In such cases, as the name implies, the engine is self-contained and bolted to a wall. Care must be taken that the engine is particularly well balanced, otherwise the wall may be shaken to a serious extent.

Before dealing with high-pressure and high-speed engines, some description may be given here of the domestic engine, so called from its supposed safety and from its suitability for use in small private installations. It is designed to work with steam at atmospheric pressure or a few pounds above it, and comprises in one body a boiler, engine, and condenser. Only a very small power can be obtained from such engines. Fig. 67 shows the Davey safety motor arrangement. It is a combination of an engine

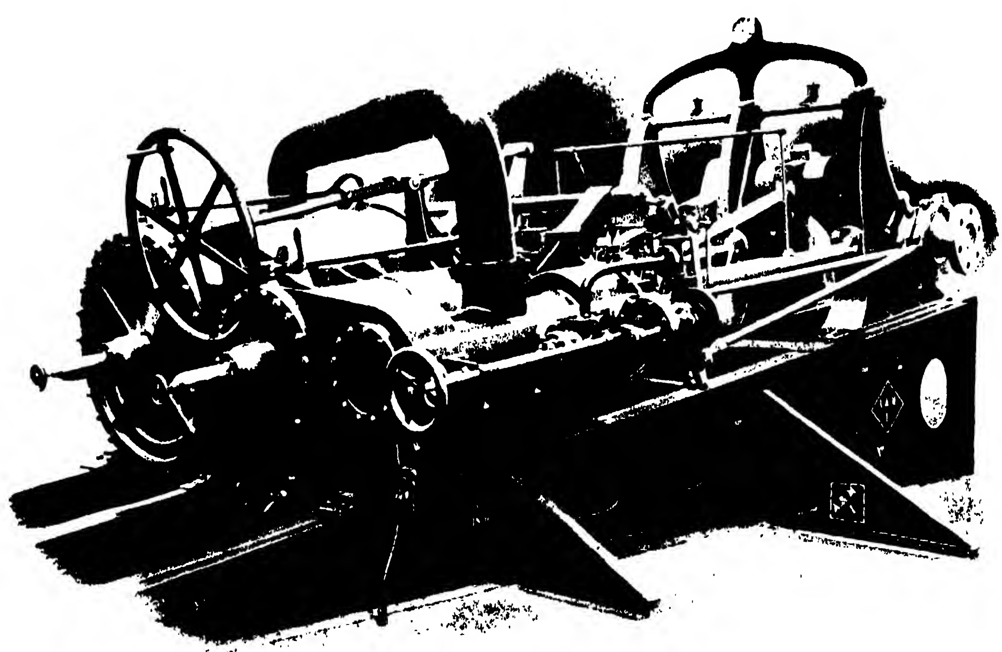


Fig 66. Diagonal Engines of Paddle Steamer

and of a vertical boiler with a condenser, which consists of a number of upright tubes arranged at the back of the boiler in a separate casing. A skilled attendant is not necessary, as the construction is of the simplest kind and little attention is required.

Safety is ensured by the low pressure, and even if the pressure should rise from any cause, the small store of water in the boiler would not cause much serious damage. To raise the necessary pressure and start the engine only about ten minutes are required.

Woolf Engine.—Hornblower's original form of compound engine, revived by Woolf, consists of two cylinders connected directly without the use of an intermediate steam chamber. As the one cylinder discharges directly into the other, the pistons require to move in unison, the one commencing its stroke as the other finishes; that is, they must act upon the same crank or on opposed cranks, or the cylinders must be arranged in tandem with both pistons on one rod. Engines in which the steam passes directly from one cylinder to the next are called Woolf engines, in contradistinction to engines in which the steam from the first cylinder passes into an intermediate receiver before being admitted to the next cylinder. As the chief advantage of compound working was unknown to Hornblower or Woolf or to many of their followers, it is probable that the object aimed at in the division of the total expansion over two cylinders was to permit of a better distribution of the forces, thus reducing the weights of the parts. For expansive working Woolf used simple slide valves on both cylinders, as shown in fig. 68. Woolf engines combine the essentials required for uniform and economical working, and have been accordingly much used for spinning and weaving mills, in spite of their relatively high price and the larger number of working parts involved.

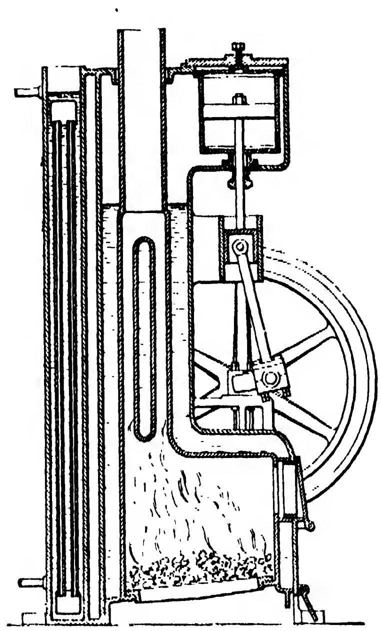


Fig. 67. Davey Motor

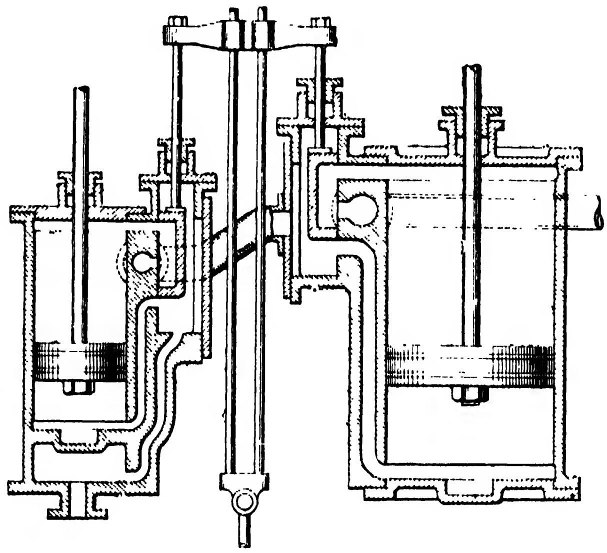


Fig. 68. -Woolf Engine

Compound Engines.—Hornblower and Woolf, by dividing the expansion of the steam over two cylinders, obtained an advantage the whole nature of which was not realized until a later date. When steam is expanded in a cylinder from a high to a low pressure the temperature falls accordingly, and the cylinder walls are subjected to a great range of temperature, being at the end of the stroke in contact with the low-temperature exhaust steam, and at the beginning with the live steam at the

boiler temperature. There is therefore, under these circumstances, a serious amount of initial condensation of the steam, involving a loss of economy. By expanding the steam in two stages the range of temperature in each cylinder is decreased and the condensation of the steam is largely prevented. When the steam pressure is higher than 120 lb. per square inch it is advisable to expand in three stages, if the range of temperature in any cylinder is to be kept within the point at which condensation seriously takes place. For triple-expansion working, however, 160 to 180 lb. pressure is used in preference to the lower pressures of 100 to 120 lb.

Receiver Engines. In the Woolf engine the cranks pass their dead centres simultaneously, so that the exhaust from the one cylinder may pass directly into the other and expand usefully there. When it is necessary to dispose the cranks at other

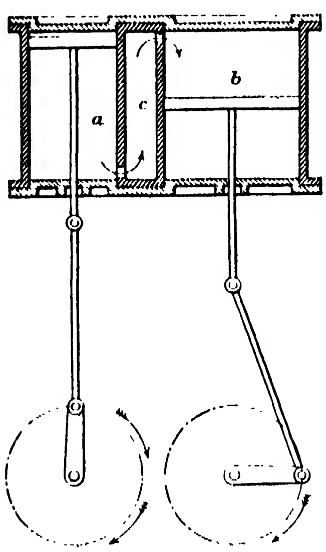


Fig. 69. Position 1

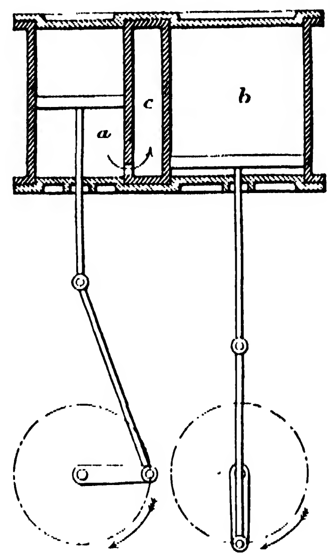


Fig. 70. Position 2

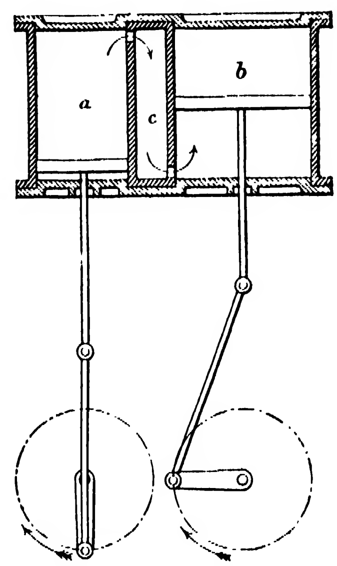


Fig. 71. Position 3

angles than 180°, say at 90°, as is generally the custom in marine or other reversible engines, where it is not desirable to have both cranks simultaneously on their dead centres, an intermediate receiver must be fitted between the high- and the low-pressure cylinders to contain the steam exhausted from the high-pressure cylinders until the right moment for its admission to the low-pressure cylinder. Figs. 69, 70, and 71 show three positions of a compound vertical engine having its cranks at 90°, by means of which the action may be explained. In position 1 the piston of the small high-pressure cylinder is about to descend, and the piston of the low-pressure cylinder is at the point where its valve is about to close, so that the steam which has entered the cylinder from the receiver may expand. Position 2 shows the low-pressure piston at the end of its stroke, when the steam from the receiver and from the high-pressure cylinder is allowed to enter under it. Position 3 shows the high-pressure cylinder completely exhausted and the low-pressure piston about half-way up. At this point, or a little before, the admission valve to the large cylinder is closed, and the steam is allowed to expand, while the other side of the piston is open to the condenser. It is very essential that there should be no drop of pressure between the high-pressure cylinder

exhaust and the receiver, as such a drop means an irrecoverable loss, and the pressure in the receiver should not fall below the final pressure of the small cylinder. This can be arranged by altering the point at which the admission to the low-pressure cylinder is cut off. By making the cut-off earlier the pressure in the receiver is increased, and by delaying it the receiver pressure may be reduced. In this way any drop in the receiver may be obviated and the work done in the two cylinders may be equalized. It is advisable in practice to allow a small drop of about 1 lb. pressure in the receiver, the loss involved being of a negligible amount. Not only the cylinders but the receiver also should be jacketed with live boiler steam, to ensure as far as possible that the temperature of the cylinder walls does not fall below that of the entering steam. It is advisable also to use live steam in the jacket of the low-pressure cylinder in preference to receiver steam, otherwise it may simply act as a wet jacket round the cylinder. All the jackets should be well drained, as the presence of water leads to further rapid condensation. The intermediate receiver may be formed in the casing between the two cylinders, or it may be a separate chamber connected by piping. Occasionally the connecting pipes are made sufficiently large to act alone as a receiver. The arrangement may be varied in endless ways to suit the conditions of working. No general rules for the proportioning of the various cylinder and receiver volumes can be given here, as these depend upon the power to be developed, the steam pressure, the speed, and other conditions. The receiver capacity should be at least equal to that of the small cylinder and not more than that of the large. Its heating surface should be about 1 to $1\frac{1}{2}$ times the inner surface of the low-pressure cylinder. In marine engines the two cylinders are provided with ordinary valves worked by Stephenson's links and controlled by the same lever, but when more complete control is desired the link gears are so arranged as to be separately controllable. When the pressures used are high a piston valve is fitted to the high-pressure cylinder in place of the ordinary **D** slide. In land engines both cylinders are generally arranged for variable expansion, the small cylinder valve being controlled by the governor while the low-pressure valve may be varied by hand in order to simplify the gear.

Advantages of Multiple Expansion.—By using two or more cylinders in which successively to expand the steam, it is possible to commence with steam at a much higher initial pressure than could be used in a single cylinder, and thus to obtain the increased economy which high-pressure steam permits of. On account of the smaller range of temperature in each cylinder, and the smaller cooling surfaces, the condensation losses are lessened. The division of the power over more than one cylinder permits of a better distribution of the load, enabling lighter moving parts to be used, and permitting of a higher speed. To obtain a sufficient total range of expansion over the cylinders it is not necessary to cut off unduly early in any one cylinder, so that it is unnecessary to use a complicated type of valve gear. Although compound engines appear more complicated, their cost compared with that of a single engine of the same power and economy, and using high-pressure steam, is less. These advantages have made the adoption of compound and triple-expansion engines universal where, as in marine work, economy is essential and high-pressure steam must be used.

Corliss Engine. The first engine of this type dates from 1850. Thereafter it was very considerably modified by Corliss, whose name is now used to distinguish the type. The admission and exhaust valves are separate but controlled together. There are thus four cylindrical valves operated from a common eccentric or "wrist plate", so as to give the necessary steam distribution. The gear may be arranged to admit steam throughout the stroke if desired. There are many designs of controlling gears, and it is not possible to do more than mention one or two of the more typical ones. Fig. 72 is a diagrammatic arrangement of the gear fitted by Corliss to many engines in Europe about the year 1852. The two admission and the two exhaust valves are operated from the circular wrist plate, which receives an oscillating motion directly from an eccentric on the engine shaft. In the case of the exhaust valves the levers L_1 L_1 are driven directly from the wrist plate, but this is not so in the case of the admission valves, which must close sharply. Springs S S hold the connecting rods of the admission valves in contact with the levers L L, and when this is so the oscillation of the wrist plate causes the valve to open. At a predetermined point of the motion, however, projections R R on the connecting rods come into contact with inclined planes M M, and are depressed until they disengage the ends of the valve levers L L, which close sharply under the action of the spring dash pots Q Q. An improved arrangement introduced by Messrs. Inglis & Spencer is illustrated in figs. 73 and 74. As before, the exhaust valves B B are driven positively from the wrist plate, but the arrangement of the trip gear for the admission valves is simpler. Each connecting rod consists of two springs which engage the heads of the valve levers. At the required moment, when the wrist plate has oscillated to a certain point, the springs are forced apart sufficiently to disengage the levers and allow the valves to close smartly under the action of the springs in the dash pots C C.

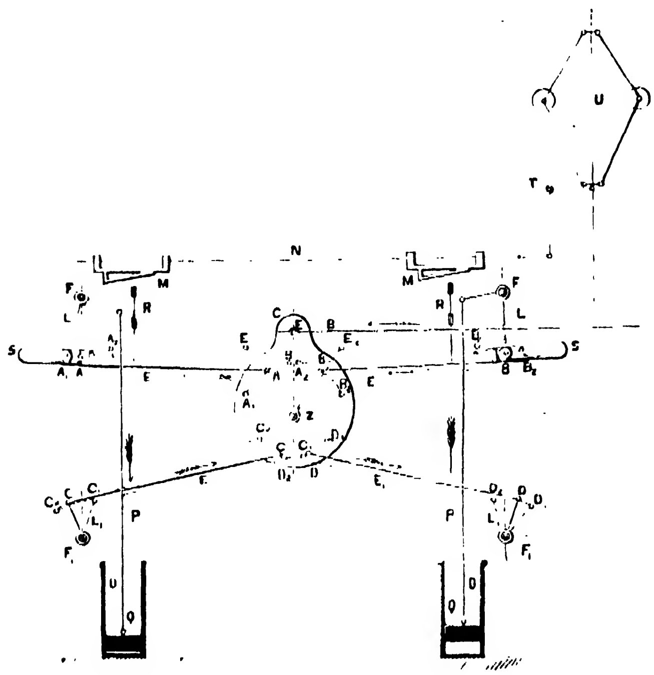


Fig. 72.—Diagrammatic Arrangement of Corliss Gear

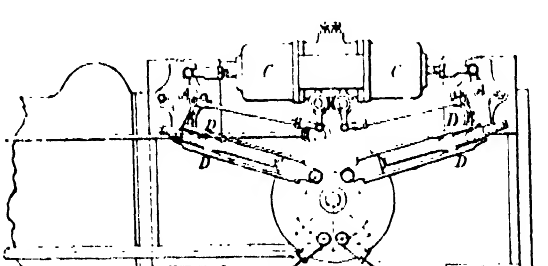


Fig. 73.—Side View of Inglis & Spencer's Corliss Gear

The Corliss valve has an attractive appearance, and works with mathematical precision provided every care is taken to keep it in good order and adjustment. For

this reason it is advisable to entrust engines fitted with Corliss gears to men who thoroughly understand and have experience of the mechanism.

Automatic Trip Expansion Gear.—In the illustration fig. 75 a long-stroke tandem compound engine, as made by Messrs. Robey, of Lincoln, is shown. It is fitted with double-beat admission drop valves operated through a trip gear, which is further automatically regulated by the governor. Generally the exhaust valves are of the simple gridiron type, but in the example given double-beat drop valves are used, driven directly without any trip gear. Fig. 76 shows the two admission valves removed from the cylinder, together with the governor and the trip gear as used. In fig. 77 a section through the cylinder and valves shows the action of the gear. All the valves are operated by means of eccentrics keyed to the shaft running alongside the engine. The balanced admission valve is raised by means of the eccentric rod, which at one point of its stroke acts upon and depresses the end of the small horizontal lever which engages the valve spindle. This point is just before the piston has reached the end of its travel. Owing to the different paths described by the ends of the eccentric rod, link, and the lever respectively, the

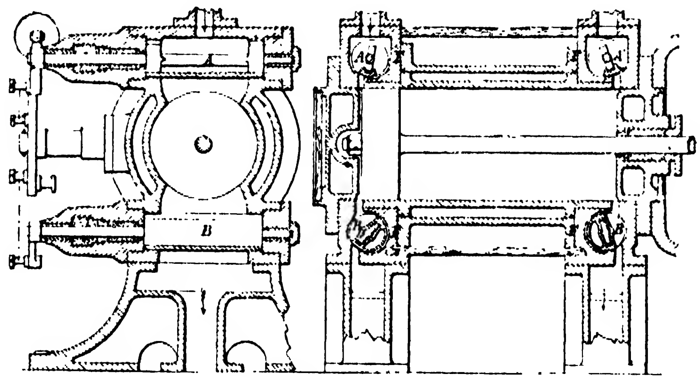


Fig. 74.—Inglis & Spencer's Automatic Trip-gear for Corliss Valves

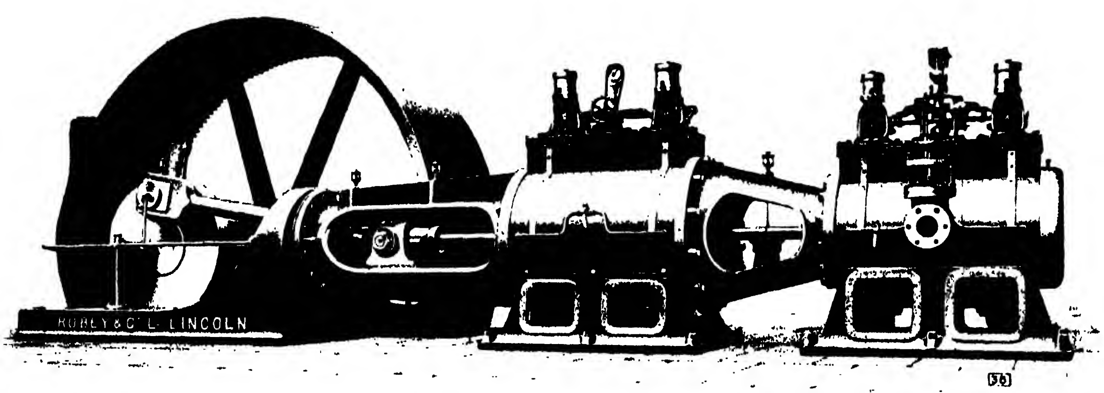


Fig. 75.—Robey Tandem Compound Engine

tripper at a certain point slips out of contact and the valve drops sharply, cutting off the steam supply. The arrangement for securing an automatic cut-off is very simple. The governor in rising moves the lever arm, and with it the pivot or fulcrum of the small lever, so that the tripper loses its contact and allows the valve to fall at an earlier period in the stroke. In this way, as the governor rises and falls, the point of cut-off is advanced or retarded accordingly. Great regularity of running under very varying loads is obtained with this controlled gear, and by the use of balanced valves.

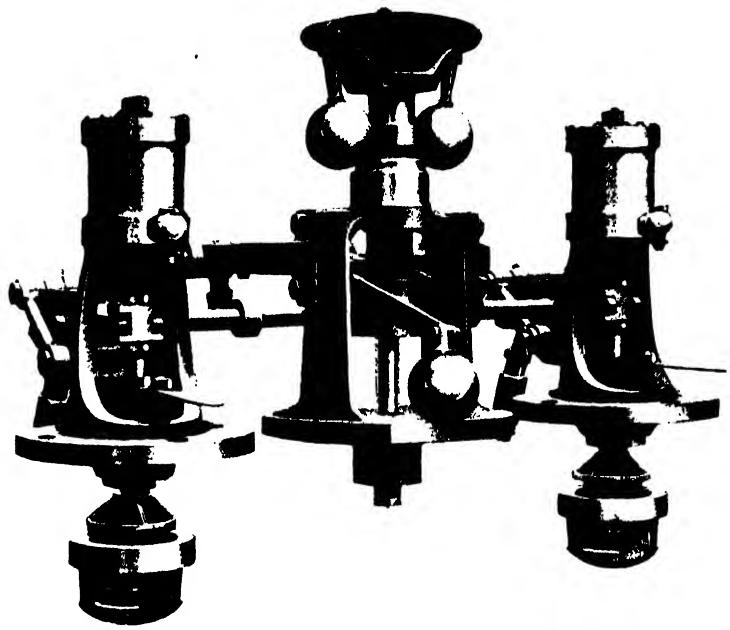


Fig. 76.—Robey Expansion Valves and Trip Gear

It is sometimes necessary to have a ready means of instantly stopping the engine, as, for example, in cases of emergency where danger to life or to the machinery is involved. To provide for this the lever arm is prolonged past the governor, and has attached to its end a cord which may be led to any desired part of the building. By pulling this cord the trip lever is pulled out of contact, the admission valves close, and remain so as long as the lever is held up.

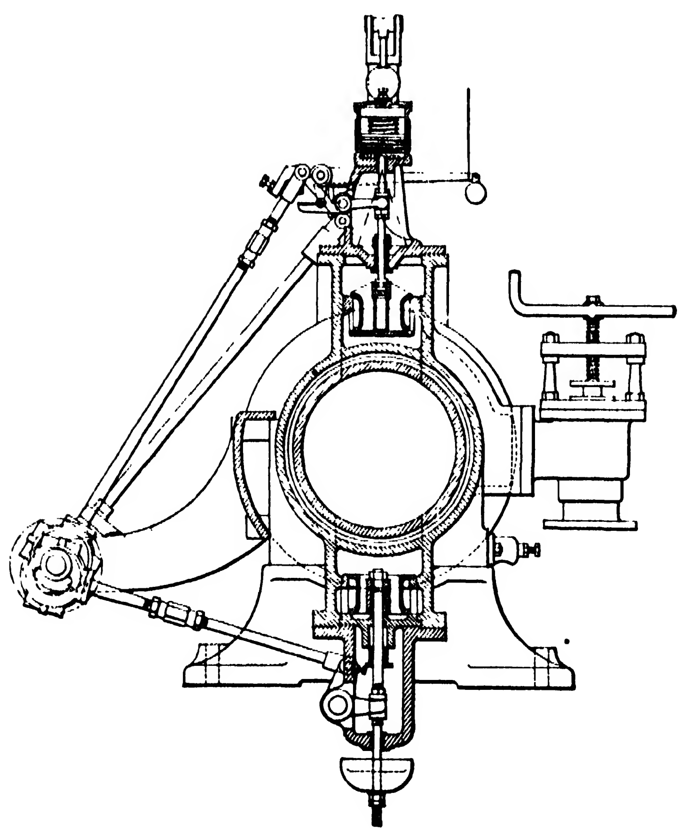


Fig. 77. Section through Valves and Gear of Robey Engine

Piston-drop Valve Engines. An example is given of a tandem compound engine as manufactured by Messrs. Cole, Marchent, & Morley, of Bradford, who hold the record for the most economical engine ever installed. The results were obtained from a compound vertical two-crank engine, using superheated steam, under test by a committee consisting of Messrs. M. Longridge, J. Taylor, J. B. Gow, and H. M. Longridge. These results are largely due to the use of piston valves which permit of highly superheated steam being used. With other types of valves, such

as Cornish or Corliss, great trouble is experienced through leakage whenever high-temperature steam is used. The Morley piston valve, fig. 58, is not affected in the same way, as the valve piston rings keep the valve tight at all temperatures. It can also be run at a higher speed, as, unlike the Cornish valve, it does not require to close down metal to metal upon a seating. Valves of this type have the further advantage of requiring very little lubrication. The saving of oil is in itself a great

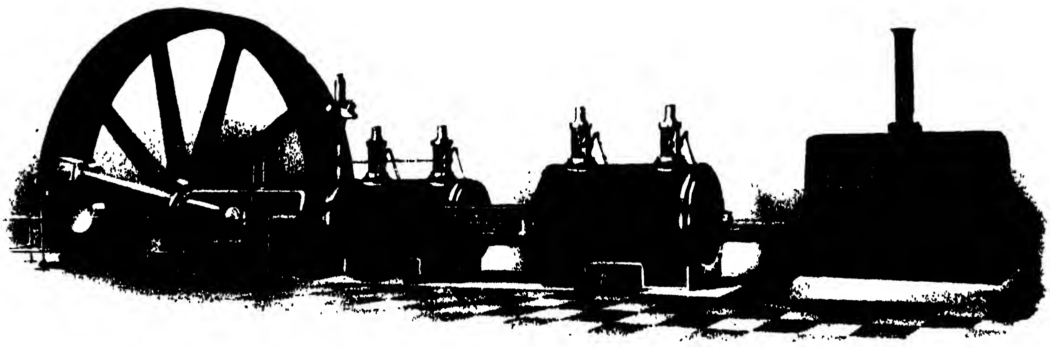


Fig. 78.—Tandem Compound Engine by Messrs. Cole, Marchent, & Morley

consideration. The economical results already referred to were obtained with steam superheated to 700° F., and were as follows:—

Mean steam pressure at stop valve, 117 lb. per square inch.
Mean steam temperature at stop valve, 740° F.
Mean vacuum in condenser, $26\frac{1}{2}$ in.
Total steam per indicated horse-power per hour at 480 i.h.p., 9.1 lb.
Total steam per indicated horse-power per hour at 333 i.h.p., 8.58 lb.

The engine tested was of the inverted compound marine type, with unjacketed cylinders, each fitted with two admission and two exhaust valves all of the piston-drop type. A surface condenser was also used.

In the illustration, fig. 78, the engine is of a horizontal tandem compound type, with the air pump of the jet condenser driven directly from the tail rod of the low-pressure cylinder. Piston-drop valves are used throughout. Piston-drop valve engines have been made with great success in Belgium by Messrs. Van den Kerchove. These engines differ only in detail from that illustrated; the common feature is the use of the piston valves, but in the Kerchove engine the piston valves are placed in chambers in the front and back cylinder covers in order to reduce as far as possible the clearance spaces.

Positive-gear Engines.—With trip gears the drop valves, unless when of the piston type, require to be very accurately adjusted, so that on closing they just touch their seatings without excessive shock; and constant attention is necessary to preserve the adjustment. To permit of rotational speeds exceeding 80 or 100, positive gears have been devised to take the place of the trip gears. The Recke-Ruston gear

manufactured by Ruston, Proctor, & Co., of Lincoln, is one example. The valve motion is obtained by the rolling contact of curved levers, so shaped as to give the desired lift without friction and without wear on the contact paths. As indicated in the illustration, fig. 79, the one cam is operated directly from the eccentric rod, while the hook cam on the valve spindle is kept in contact by means of an adjustable spiral spring. Regulation is effected by a special governor acting upon the eccentric which controls the valve.

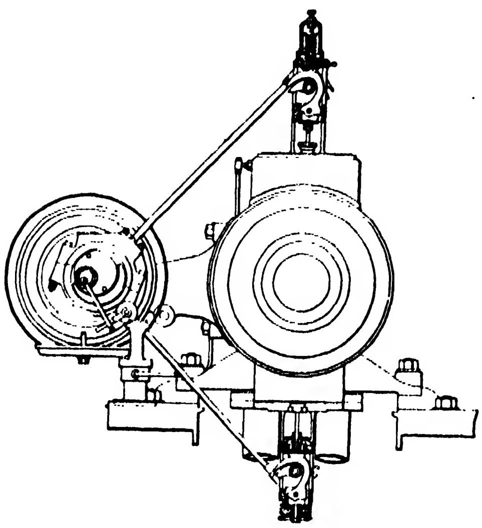


Fig. 79. Recke Ruston Gear by Ruston, Proctor, & Co.

Sulzer Engines.—A four-cylinder triple-expansion engine by Messrs. Sulzer Bros., of Switzerland, is shown in fig. 80. Engines of this type are made for normal outputs of from 250 to 6000 h.p., using steam at from 140 to 200 lb., and work in conjunction with a condenser. According to the size and pressure the consumption varies from 12 to 11 lb. of saturated steam per indicated horse-power hour. By superheating the steam to from 380° to 650° F. this consumption may be reduced by $\frac{3}{4}$ to $2\frac{1}{4}$ lb. There are two low-pressure cylinders placed in tandem with the high-pressure and the intermediate cylinders respectively.

The admission valves and the exhaust valves, of each of which there are two fitted

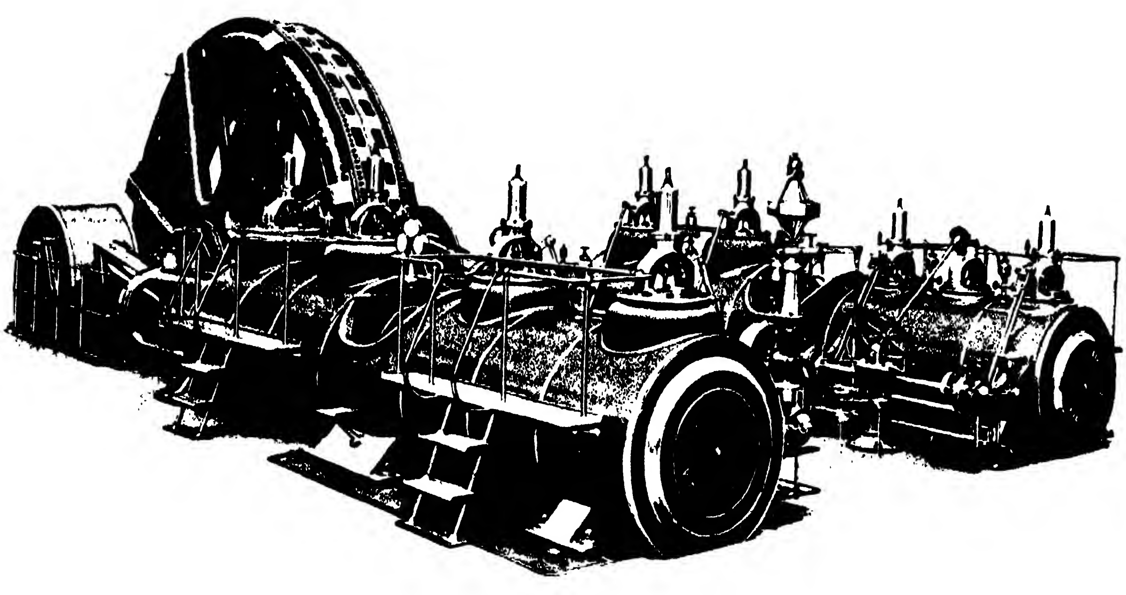


Fig. 80. Four-Cylinder Triple Expansion Engine by Sulzer Bros. of Switzerland

to each cylinder, are shown in fig. 81. They are almost perfectly balanced, and have each two or more conical seating surfaces. Ample diameter, combining large port area with small clearance, is provided. The peculiar construction of the valve renders it

lastingly steam-tight, and suitable for high-pressure or superheated steam and for comparatively high speeds. On the high-pressure cylinder the admission valves are controlled by a trip gear, which is varied automatically by the governor from 0 to 55 per cent cut-off, corresponding to the load, thereby ensuring uniform working and minimum steam consumption. They are provided with air dash pots for soft closing. The admission valves on the intermediate and low-pressure cylinders have a constant cut-off adjustable by hand. All other valves are operated through rocking levers or cams, which afford very favourable leverage at the moment of opening, then quick motion both ways, and finally a soft closing action. The cylinders are steam-jacketed throughout with live steam, which is also led around the main valves, and particular attention is paid to the drainage of the jackets and cylinders.

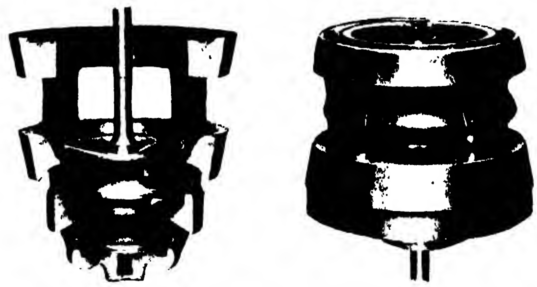


Fig. 81.—Sulzer Valves

Wheelock Engines.—In the Wheelock engine all the valves are placed on the under side of the cylinders where these are horizontal, so that the condensed steam readily drains away. The admission and exhaust valves at each end are combined

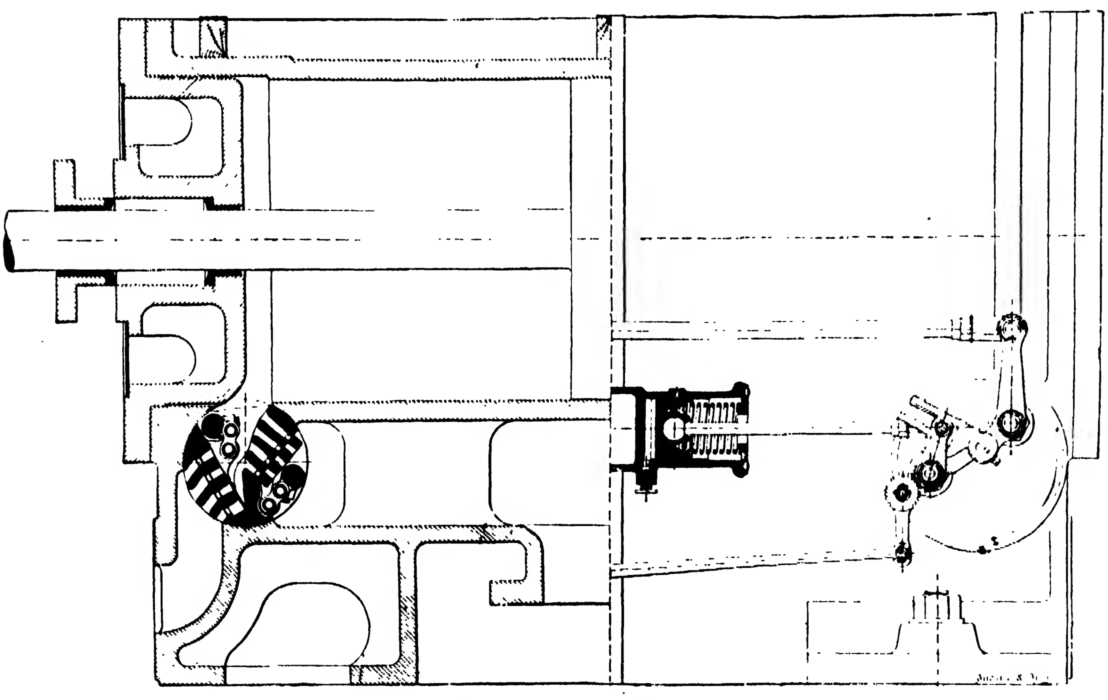


Fig. 82.—Wheelock Engine Valves and Gear

in one casing, as indicated in the sections of a Wheelock engine made by Messrs. Daniel Adamson & Co., of Dukinfield, figs. 82 and 83. The valves and seats are of the flat grid type, giving a large port area for a small travel, and small frictional surfaces. Almost instantaneous opening and closing are obtained, with ease of action under extreme pressures, by the use of a toggle joint, as shown in the section fig. 82. The

arrangement also allows the valve practically to rest during the periods of exhaust and of steaming. One chest at each end of the cylinder contains both the steam and exhaust valves, the seatings being formed in a tapered plug which fits into a bored seat in the cylinder. The wearing parts are thus all self-contained and may be readily replaced. All the valves of each set of tandem cylinders are, in the Wheelock expansion gear, controlled by one eccentric. Automatic control of the expansion is

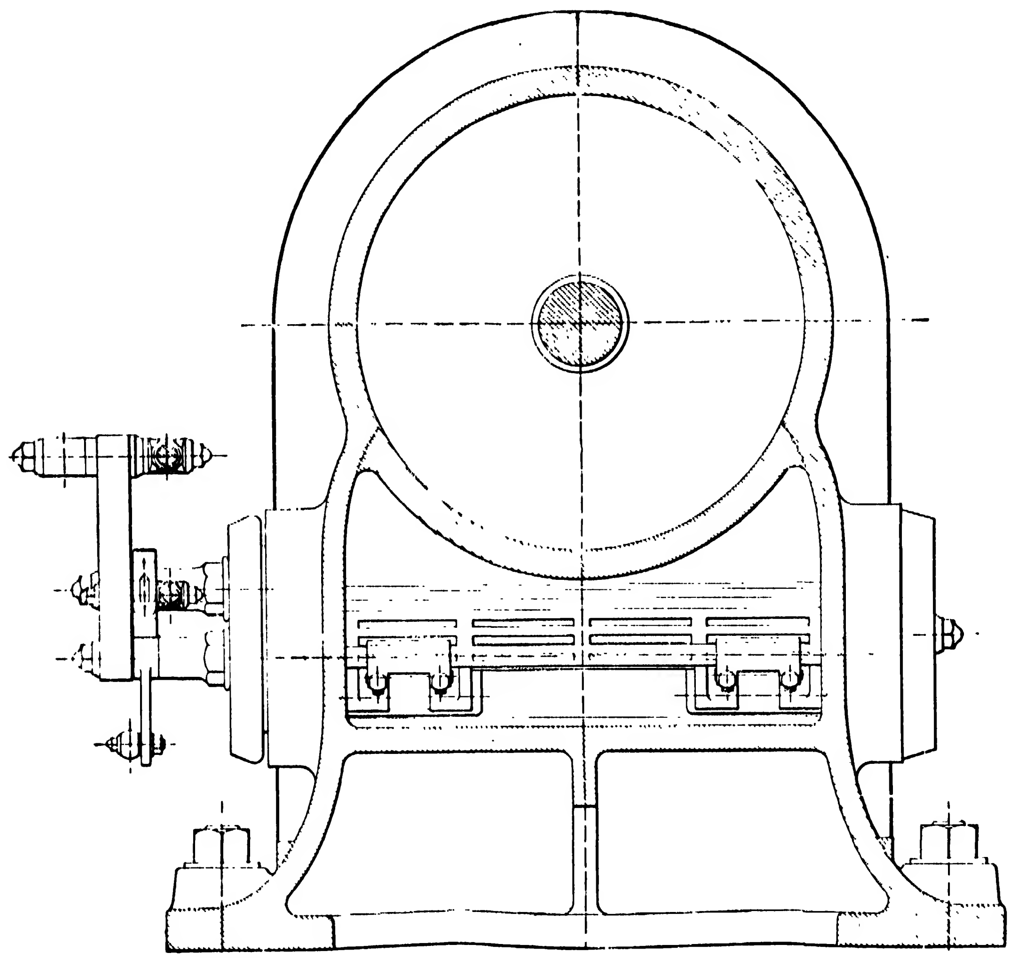


Fig. 83.—Wheelock Engine. End Section through the Cylinder

obtainable from zero to 75 per cent of the piston stroke, whilst retaining complete control of the periods of release and compression.

High-speed Reciprocating Engines or Quick-revolution Engines.—By high speed is meant not high piston speed, but a high speed of crank rotation. In high-speed engines the piston speed is not in general greater than that of slow-speed, long stroke engines, in which the piston velocity may vary from a mean of 400 ft. per minute to 800 or 900. High-speed engines, such as are used for torpedo boats, are, however, frequently made with a piston speed of as much as 1000 to 1200 ft. per minute. On account of the weight of the moving parts it is not advisable to exceed a piston speed of 800 ft. per minute. As the power obtainable from an engine is proportional to the steam volume per unit of time, and the mean pressure, in order to increase the number of revolutions without increasing the piston speed the length

of stroke must be correspondingly diminished. High rotational speed results therefore in a great diminution of weight, not only of the engine body but of the moving parts. A comparison of a slow-speed engine, say for marine merchant service, and a high-speed torpedo-boat engine of equal power shows this very effectively. A 3000-h.p. engine running at 75 revolutions may weigh over 500 tons, while a torpedo-boat destroyer engine of equal power, running at 400 revolutions, need not weigh 25 tons.

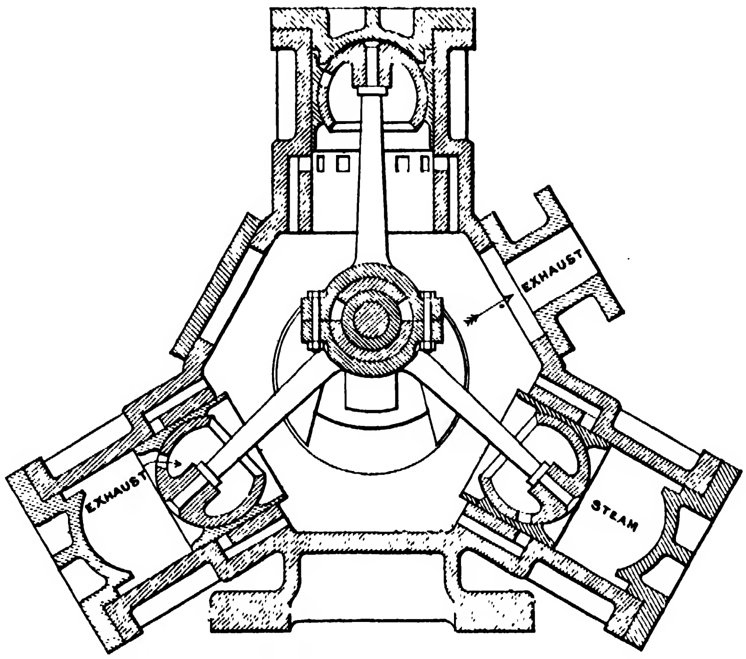


Fig. 84.—Brotherhood Three-Cylinder Engine. Side Section

The need for high-speed engines arose with the development of electric lighting and traction, as it was found more desirable to drive the dynamos directly than by means of belts or gearing. In 1873 Mr. Brotherhood introduced what was practically the first high-speed engine suited for the driving of dynamos. It is a single-acting engine

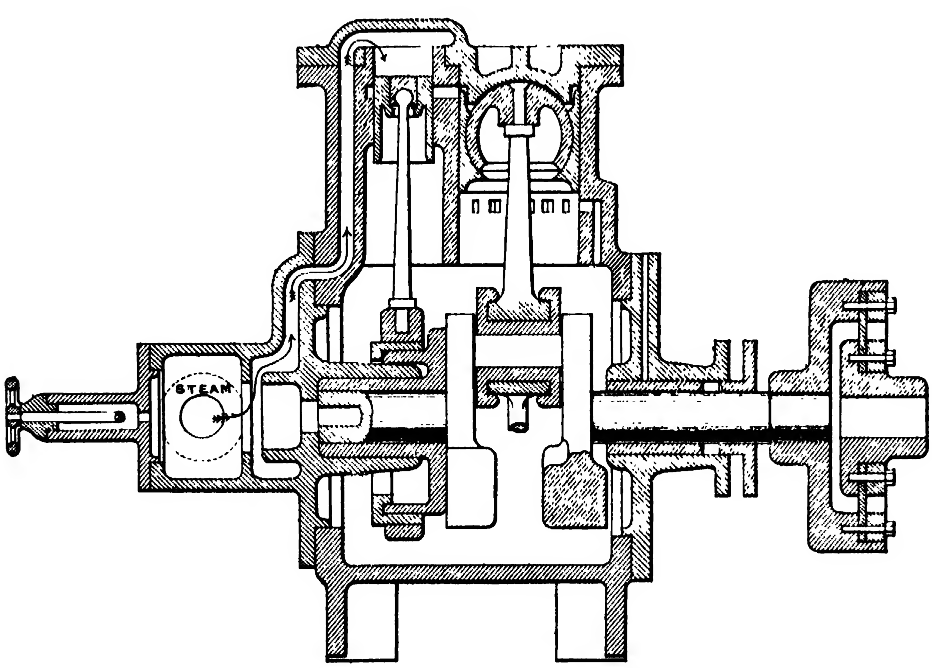


Fig. 85.—Brotherhood Engine. Side Section through Cylinder and Valve

having three pistons coupled to one crank shaft. Sectional elevations are given in figs. 84 and 85. The cylinders are disposed at 120° around a central casing, which

serves as an exhaust chamber. As the engine is single-acting, bucket pistons are used in order to dispense with intermediate connecting rods and to reduce the moving weights and the size of the engine. Use is made of the spherical oscillating connection of the piston and rod head by making it uncover a supplementary exhaust port, which remains open during part of the back stroke. Steam release is effected by the piston uncovering exhaust ports in the cylinder wall. Three piston valves worked from a common eccentric distribute the steam to the working sides of the pistons. A centrifugal governor in line with the shaft acts upon a throttle and thus regulates the speed as the load fluctuates. Many of these engines have been built not only for running dynamos and fans but also for use with compressed air. As steam engines they are being entirely displaced by the double-acting high-speed engine.

A very uniform turning moment and freedom from vibration is obtained by the disposition of the three cylinders, and, as the cylinders are single acting, the stress on the crank pin never changes from push to pull, as in the ordinary double-acting reciprocating engine.

The Willans and Robinson Central-valve Engine.—Until recently the Willans and Robinson engine was greatly favoured for the direct driving of high-speed machinery, owing to the uniform turning moment on the crank shaft and the freedom from shock at high speeds, and also on account of the very economical results obtained by them. By the introduction of forced lubrication, Messrs. Belliss & Morcom have made it possible to run double-acting engines at high speeds with practically no shock and but little wear. As a result, the double-acting engine is rapidly displacing the single-acting engine from its hitherto favoured position. The excellent reputation earned by the Willans engine has been to a large extent due to good workmanship and design. When, however, a breakdown of the engine does occur, the results may be very disastrous. A somewhat detailed description of the engine is given, as the design is of a most interesting and novel kind.

The engine is built either simple, compound, or triple, according to the working steam pressure, and with one, two, three, or more cranks, according to the power and the uniformity of drive required and freedom from vibration. In the simple engine there is one cylinder arranged over each crank. When the engine is compound a high-pressure cylinder is placed in tandem over each low-pressure cylinder, and similarly, for triple expansion, three cylinders in line act upon each of the cranks. This arrangement distinguishes the Willans engine from other high-speed engines. The chief advantages gained are: an equal distribution of the work over all the cranks under all conditions of load; more uniform turning moments; and a gain in economy due to the more thorough cylinder drainage that is possible compared with that obtainable with any side-by-side arrangement of the high- and low-pressure cylinders. Efficient drainage is facilitated by the use of the Willans central-valve arrangement described later.

Fig. 86 shows a simple engine direct coupled to an electrical generator, and fig. 87 shows the arrangement of cylinders in the compound engine. The cylindrical vessel on the right-hand side is a steam separator, which is always provided to ensure a supply of steam as free from water as possible. As the engine is single-acting, all the moving parts are in constant thrust. In double-acting engines, on the other hand,

there is a reversal of the stress at the end of each stroke, which at high speeds involves severe knocking and wear unless special precautions are adopted. The Willans engine does not suffer in this way, there being no reversal of the stresses and no consequent knocking. Only very light upper caps are used on the main-shaft journals, as the shaft is always forced downwards, and similarly, as the big end of the connecting rod always presses on the crank pin, a small narrow bottom cover only is required. This permits of more efficient lubrication and more silent running. As will be seen from figs. 86 and 87, and from the section fig. 88, the engine is completely enclosed. At every revolution the cranks dip into the oil and water which partially fills the lower

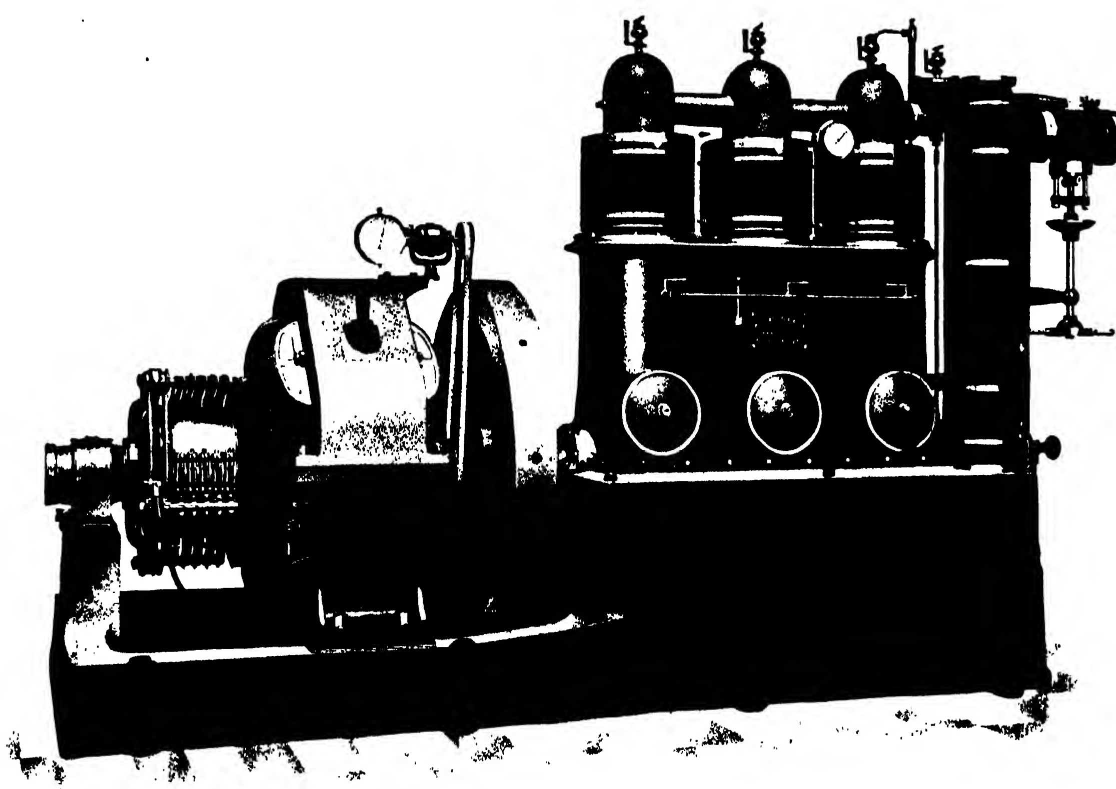


Fig. 86. Willans Simple Three-Crank Engine

casing; and thus as the cranks rotate the oil is splashed over all the working parts, so as not only to lubricate but also to cool them.

Simple expansion engines are generally supplied for pressures below 100 lb. per square inch., compound for pressures between 100 and 160 lb., and triple-expansion for pressures above 160 lb.; but these figures frequently vary with other conditions. Similarly, condensers may or may not be fitted, their use being determined by considerations apart from the engine, such as the supply or cost of cooling water. Superheated steam is frequently used. The symmetrical design of the engine, the use of piston valves with simple spring rings, and the total absence of steam packing and other features all favour the use of high-temperature steam; but the difficulty of obtaining a suitable oil limits the temperature to about 550° F. at the engine stop valve. As already mentioned, the Willans engine consists essentially of a separate engine driving

each of the cranks. In this way a very uniform turning moment is obtained at all loads. When the high-, intermediate-, or low-pressure engines act side by side upon different cranks, as in other engines, it is possible to arrange for an equal distribution of the work at one load, but not at all. The Willans engine is therefore excellently suited to the driving of large multiphase generators in parallel under varying loads.

Sufficient of the essential details are illustrated in fig. 88 to make the action of the engine clear. The figure shows a compound two-crank engine with the pistons

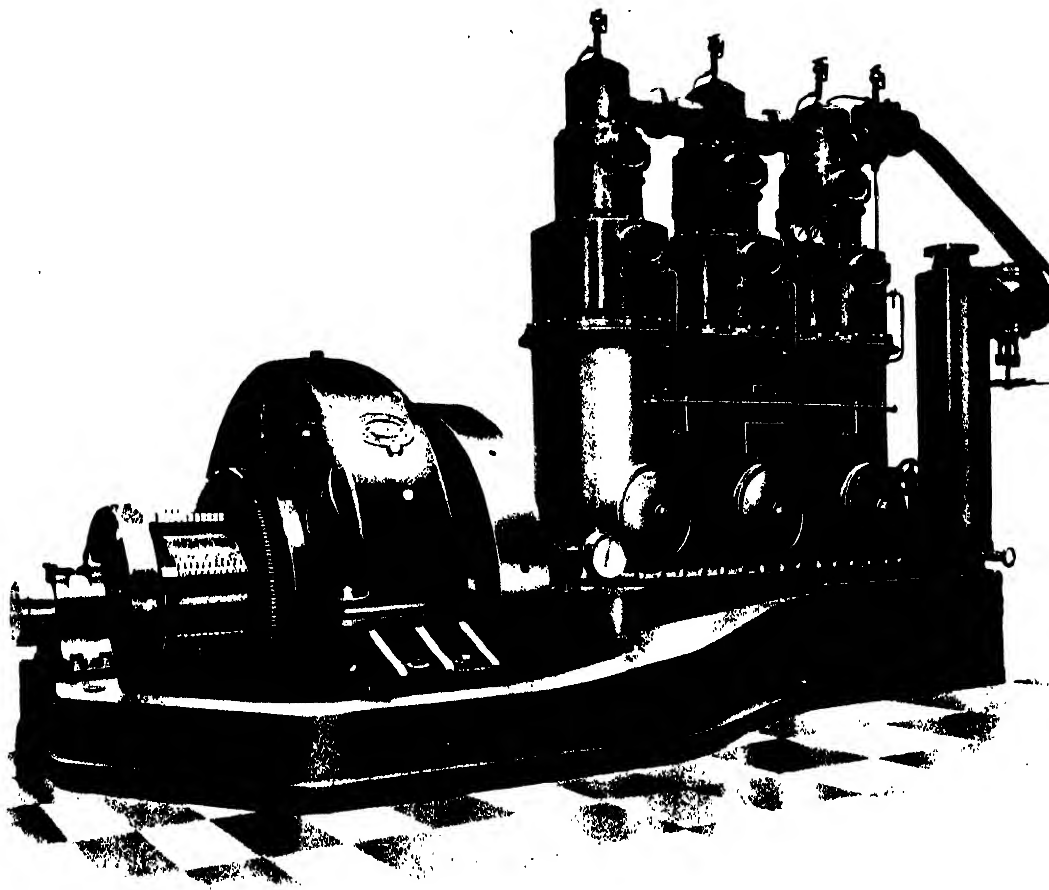


Fig. 87.--Willans Compound Three-Crank Engine

and valves in position but the connecting and eccentric rods removed. At the top is placed the high-pressure cylinder with the low-pressure beneath it. The third cylinder, which serves as a trunk for the crosshead, acts as an air buffer to ensure that the thrusts on the moving parts never change to pulling stresses. In this way knocking at the brasses is eliminated, and silent running is ensured.

It should be noted that this air compressor does not involve any serious loss of power, as the compressed air gives up its energy again on the driving stroke.

The piston rod is a hollow trunk pierced with suitable steam ports, and encloses a series of piston valves carried together upon one rod. Motion is communicated to the valves by means of eccentrics carried upon the crank pins between the connecting rods coupled to each line of pistons. By carrying the eccentrics upon the crank pins

the valve and pistons move together, while the setting of the eccentric gives the valve a certain travel relatively to the ports in the trunks of the pistons. In this way any required distribution can be arranged for. The cut-off is determined by the height of the gland on the cylinder top into which the trunk disappears.

Steam is admitted to the upper chest by means of a piston throttle valve controlled by a centrifugal governor on the main shaft, and passes through the port holes in the

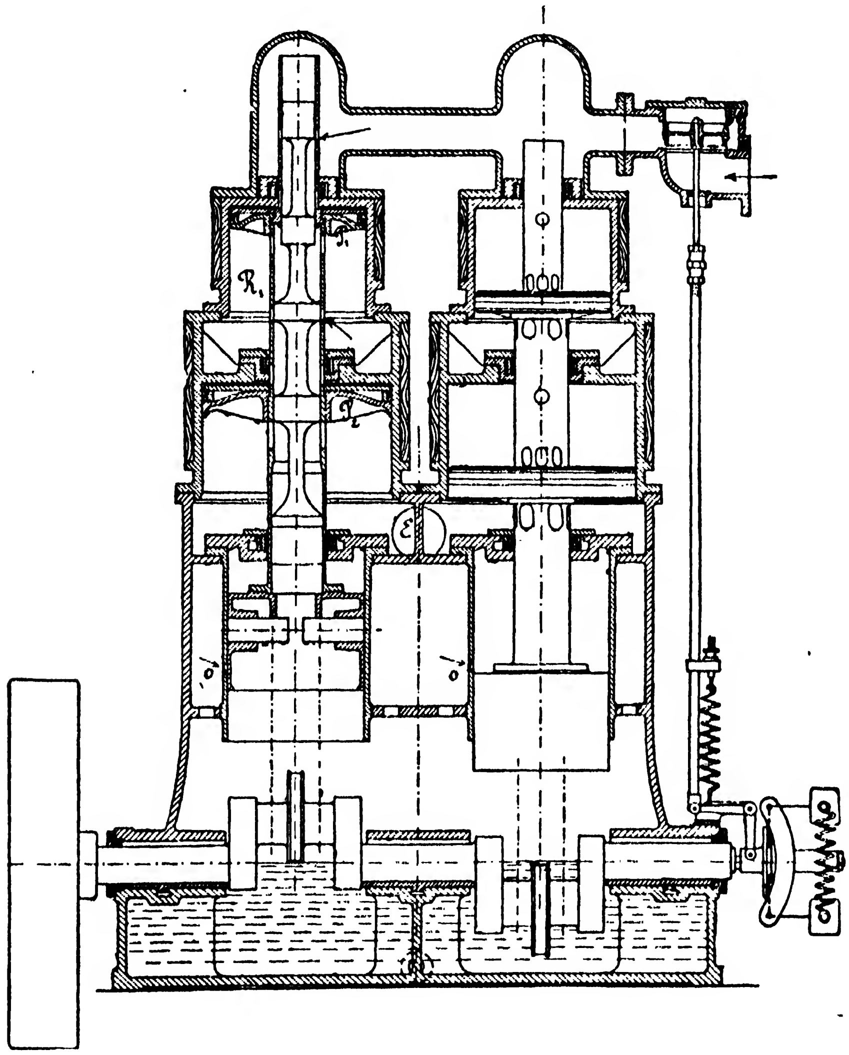
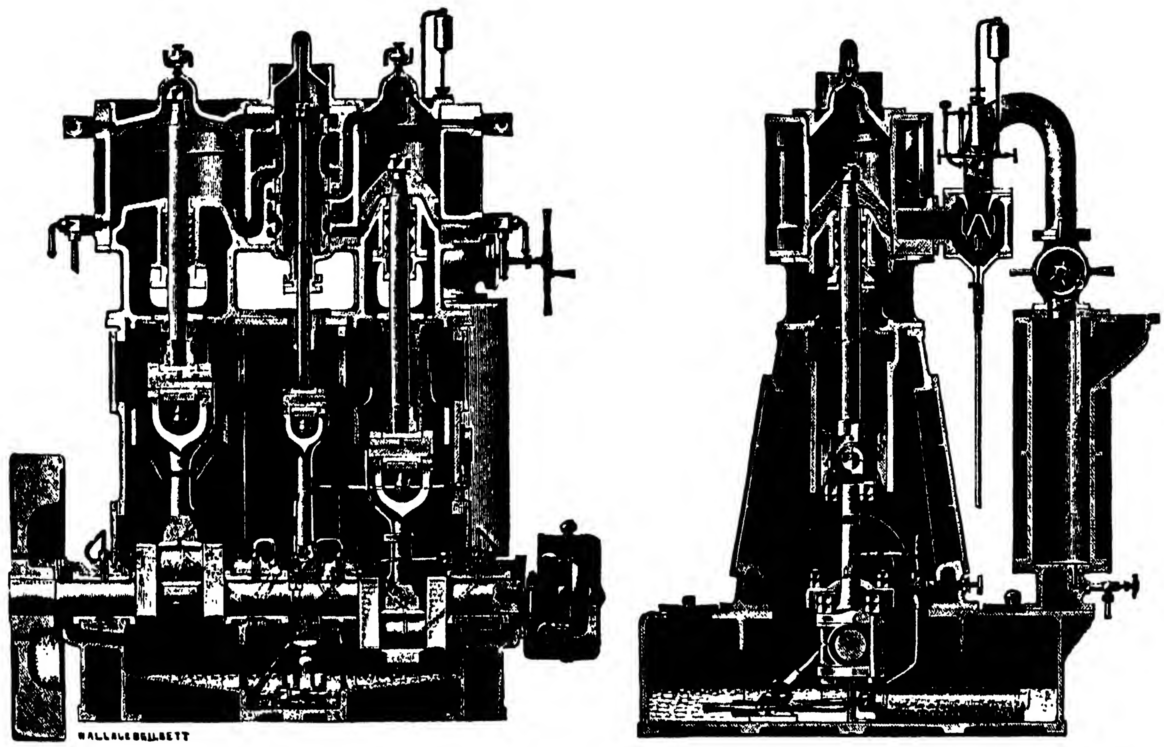


Fig. 88.—Section of Willans Compound Two-Crank Engine

valve trunk into the high-pressure cylinder. As the pistons move down, the admission ports in the trunks disappear into the cap gland, and so cut off the supply. The point of cut-off can be adjusted by altering the height of this gland. On account of the setting of the eccentric the valves have a travel relatively to the trunk, so that the second piston valve as it moves closes the port and then passes it, allowing the steam to exhaust at the correct moment into the space beneath, which acts as an intermediate receiver. A similar arrangement of glands and valves and ports determines the subsequent distribution of the steam to the succeeding cylinders and finally to the exhaust.

The Belliss Double-acting Self-lubricating Engine.—Until the introduction of forced lubrication by Messrs. Belliss & Morcom, of Birmingham, the double-acting engine could not compete with the single-acting quick-revolution engine for silent running. As already explained, silent running is secured in the single-acting engine by the provision of an air buffer, which prevents a reversal of the stresses at each end of the stroke. In the double-acting engine the stress reversals cannot be removed, although the objectionable results, so far as silent running and wear are concerned, may be almost entirely eliminated by the adoption, in conjunction with careful design, of the system of forced lubrication introduced in the Bellis engine in 1890. If the conditions be considered which



Front Section Side Sectional Elevation

Figs. 89, 90.—The Belliss & Morcom Double-acting Engine

exist between a journal and its brasses when under a load which continually reverses, such, for example, as exist at the crank pin, it will be seen that the top and bottom halves of the bush alternately transmit the driving force, and that, while the one half in this way bears upon the pin, the other half becomes separated by an intervening space. This repeated opening and closing of the parts results, at quick revolutions, in severe knocking and wear, unless special precautions are taken, such as forced lubrication.

Oil is pumped, by means of a special force pump, into the space which opens between the bush and pin under a pressure of from 10 to 20 lb., depending upon the speed of rotation and the load. As the space closes, the oil is forced out partially. The space has opened again, however, before the layer of oil has had sufficient time to be wholly expelled, with the result that the metal surfaces are constantly separated by a cushion of oil, which not only prevents knocking but also almost entirely prevents heating and

consequent wearing of the bearing surfaces. The oil is caused by the force pump to circulate in this way through all the bearings, and is used over and over again.

Two sectional views (figs. 89 and 90) are shown of a compound two-crank engine, from which it will be seen that the cylinders are arranged side by side, with between them a piston distribution valve common to both and worked by a single eccentric. An essential feature of the Belliss engine is the small number of moving parts adopted. The cranks are disposed at 180°, and steam is admitted simultaneously to the top of one cylinder and the bottom of the other. To enable the engine to work, if required,

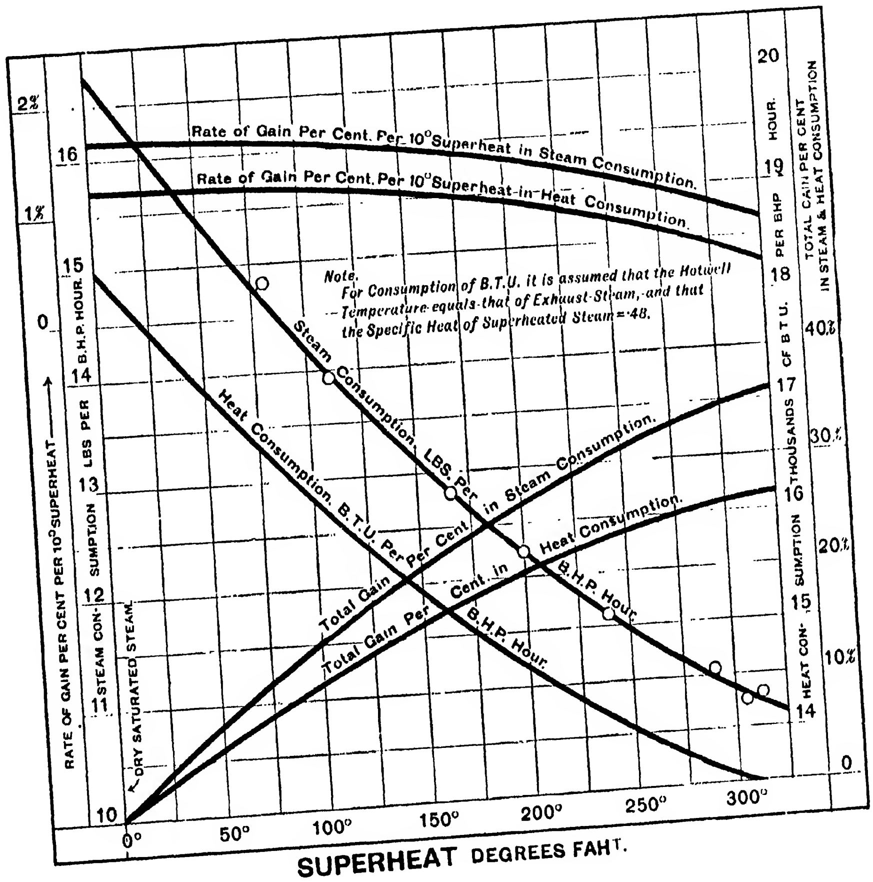


Fig. 91

under an overload, a by-pass is arranged, through which high-pressure steam may be admitted to the large cylinder. While so working, the extra load is of course carried at the expense of the economy.

In double-acting engines each piston gives two impulses per revolution to the crank shaft, while in the single-acting engine there is only one. For this reason the weight of the double-acting engine for a given power is not so great, and it is possible with less than three cranks to obtain a more uniform turning moment even at considerably varying loads.

Special attention has been devoted to the question of efficient drainage of the cylinders and to the employment of superheated steam, which is recommended up to a temperature of 500° F. at the engine stop valve. The above diagram (fig. 91)

shows the results obtained by Messrs. Belliss & Morcom from one of their 300 h.p. triple-expansion engines, using steam superheated to various degrees. Very approximately the results show that if the steam be superheated at the boiler sufficiently to neutralize condensation in the steam piping, so that the engine may receive steam that is just dry, the saving in steam should amount to about 5 per cent. For every extra

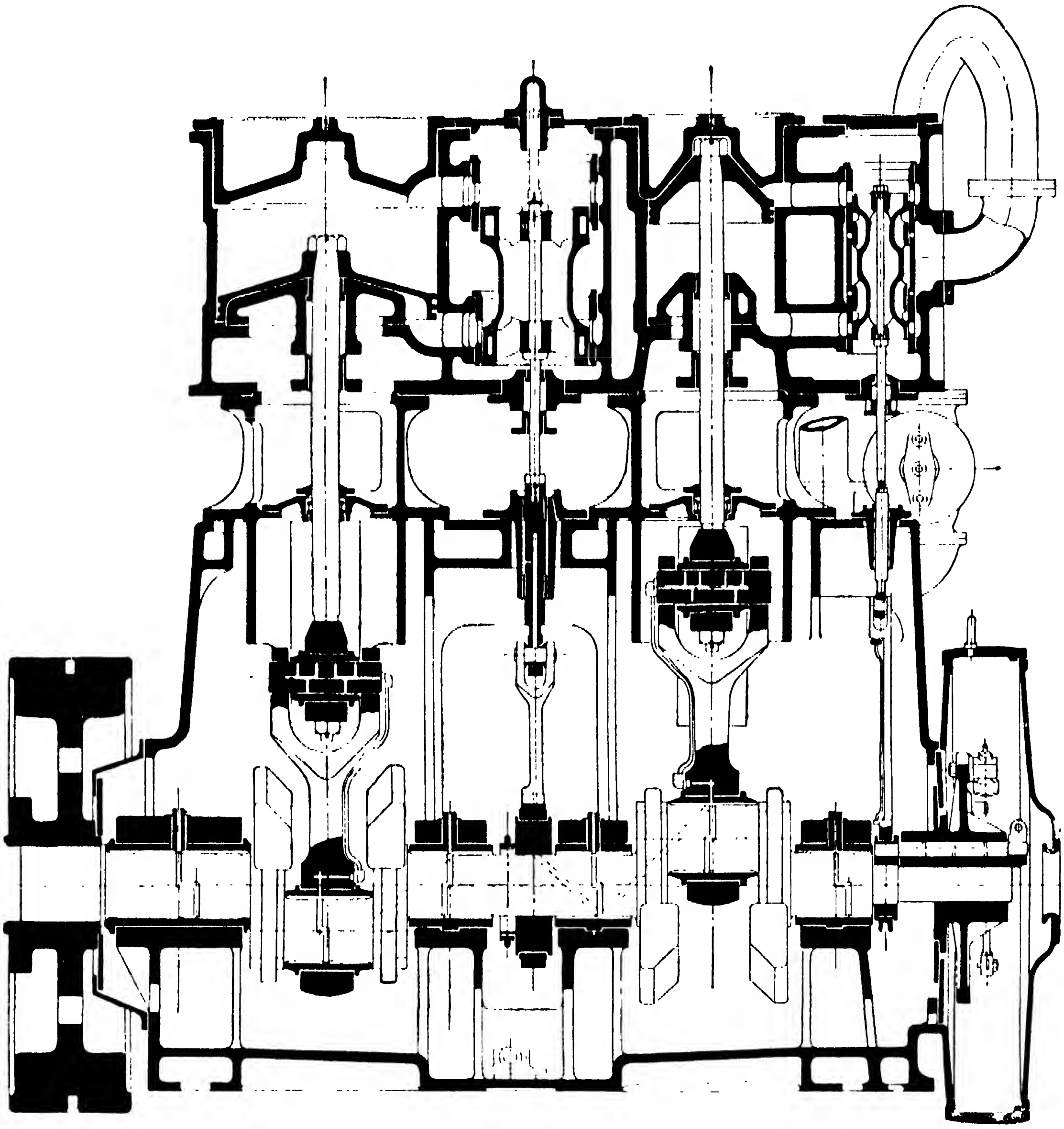


Fig. 92.—Quick Revolution Compound Engine by Messrs. Galloway Ltd. of Manchester

10° F. of superheat there should be a further economy of 1 per cent, so that the total gain for 100° should be about 15 per cent. It frequently happens, however, in installations, that the economy, so far as steam consumption is concerned, is balanced by the extra fuel indirectly required to superheat the steam. For example, the steam may be superheated by the abstraction of heat which otherwise would be utilized almost as efficiently in the feed water heaters. The actual economy obtainable in any particular case should be carefully considered in relation to all sections of the installation.

The Galloway High-speed Engine. The system of forced lubrication already described is used in the double-acting engines manufactured by Messrs. Galloway, Limited, of Manchester. Unlike the Belliss engine the Galloway compound engine has separate piston valves and eccentrics fitted to each cylinder. The triple-expansion engines of both firms are also fitted with separate piston valves. A sectional view through the cylinders and valves is given in fig. 92. What has already been said regarding double-acting engines applies in general to this engine. The chief features of the design are the ample proportions of the parts, and the extra large bearing surfaces considered desirable by the makers.

THE MANAGEMENT OF STEAM ENGINES

Starting Non-expansion Engines. If the engine is of the vertical or diagonal type the piston should, before starting, be brought towards the upper end of the cylinder, so that the steam, by first entering under the piston, may drive the condensed water away through the drain pipes at the lower end of the cylinder. Otherwise, if the piston is at the bottom and steam enters above it, the condensed water from the steam pipes will collect in the cylinder, and on the down stroke will offer considerable resistance as it is expelled through the restricted passages, or the relief valve if such is provided. The shocks may be so great as to cause serious damage to the parts, and, if the entrance of steam is too sudden, the cylinder cover may be fractured by the sudden shock of the water. It is indispensable, therefore, that before starting the engine the drain cocks should be opened, so as to expel the condensed water from the cylinder and piping where it is likely to accumulate. During running the drain cocks should occasionally be opened to allow the water that may have gathered to escape. When the cylinder is horizontal the starting position of the piston is immaterial, provided it is not on one of the dead centres. The engine may be most readily set in motion when the piston is at its mid stroke with the crank a little past the vertical position. To start the engine the steam should be turned on gently at the boiler, and then admitted to the engine very gradually by opening the regulator, so as not to cause sudden and violent shocks. Steam mixed with a considerable proportion of water will escape at first from the drain cocks, which should all be left open until the engine is well under way and only dry steam escapes. They should then be closed. After the engine has run for some time at a slow speed, the steam supply may be gradually increased, until the required speed is attained. By proceeding cautiously in this way the engine is not subjected to sudden shocks, which otherwise would occur if it were compelled to overcome more suddenly the resistance of the load. Apart from the danger to the engine itself there is the possibility of fracturing the piping, if the hot steam is admitted suddenly instead of gradually. The sudden change of temperature may quite readily result in fracture, especially if the piping is not quite free to expand.

Boiler explosions have also sometimes resulted from the sudden opening of the valve. The sudden rush of steam may cause a rapid fall of pressure, and consequently set up violent ebullition in the boiler and surging of the water. If any part has by

accident become overheated, the surging may result in a sudden evolution of steam and rupture of the overheated plates. Steam should therefore only be admitted very gradually to the engine, in order not only to warm the cylinder and expel the condensed water but also to avoid accidents to the engine and to the boiler.

Starting Expansive-working Engines.—The precaution already mentioned as necessary when starting non-expansive engines should also be observed when starting engines that work expansively; but it is not possible in the same way to warm the cylinders throughout their length, as the piston must be, when starting, near the end if a full admission of steam is to be obtained. A small supply of steam should therefore be first admitted to expel the condensed vapour through the drain cocks, and the fly-wheel pulled round several times by hand. In this way the water may be all expelled and the cylinder heated up. When the escaping steam appears dry, the cocks should be closed and the steam supply gradually increased, until the engine runs at the required speed.

Starting Condensing Engines.—Since condensing engines vary greatly in form, according as they are of a horizontal or a vertical type, or arranged to work expansively or non-expansively, no particular rules applicable to all cases can be laid down for the starting of such engines. In ordinary cases the condenser injection cock should be partially opened at the moment when the engine starts under the action of the steam, and as a greater quantity of steam is admitted to the cylinder the cock should be proportionately opened. If the engine works under normal conditions, and the condenser is in good order, the air pump will be able to remove the hot condensed steam, the condenser will not become excessively heated, and a sufficient vacuum, as indicated by the vacuum gauge, will be obtained. By admitting at first only a small quantity of steam the condenser is better able to raise the vacuum necessary for normal working of the engine. If, however, the condenser is defective, or if it is necessary to supply a large quantity of steam to the cylinder in order to start the engine under a heavy load, it may happen that the condenser cannot immediately act effectively, unless the vacuum is produced by some artificial means. The simplest way of doing this is to warm the condenser before starting the engine, by supplying it with steam through a cock provided for this purpose. The air in the condenser heats and expands, and by lifting the air-pump valves escapes to the atmosphere, so that if the condenser is then cooled by spraying cold water over the outside of the casing the vapour is condensed and a vacuum sufficient for the starting of the engine is obtained. If a special steam-supply pipe is not fitted to the condenser, the same effect may be obtained by allowing the exhaust steam from the cylinder to heat the condenser. Then on momentarily stopping the engine, and by condensing the steam as before, a vacuum may be produced, provided there are no defects in the condenser or pump.

Attention during Running.—The engine attendant should carefully supervise the piston valves and glands to detect any leakage as soon as it may occur. Apart from the loss of steam, and consequent waste of fuel, the tendency is for the leak to increase on account of the corrosive action of the steam upon the metal. Corrosion proceeds very rapidly under these circumstances, often to such an extent as to necessitate the complete replacement of the parts. Prudence of the most elementary kind demands

the stoppage of any leakage as soon as possible after it is noticed. Unless this is done the condition of the engine will rapidly deteriorate, frequent and extensive repairs will become necessary, and the attendant will not be able to obtain the best results from his engine. When the engine is new, the good condition of the piston and the valves should be daily verified; and if the attendant is starting the engine for the first time, he should first by a thorough inspection make himself familiar with the details of the mechanism he has to attend. Thereafter, when thoroughly familiar with the engine, his inspections of all the parts should be made at intervals not exceeding two months. The piston packing and the glands will require more frequent overhauling than any other part of the engine. To keep the piston steam-tight two methods are most frequently employed. The sides of the piston may be formed in segments, which are pressed outwards against the cylinder walls by means of internal springs of very varied design. In the second method the steam-tightness depends upon piston rings fitted into grooves around the piston. These rings are made of steel or sometimes cast iron turned to a diameter about one-tenth larger than the internal diameter of the cylinder. A small piece is then cut from the ring, so that it may be sprung over the piston into the groove on its face. When the piston is replaced in the cylinder the ring presses outwards with a gentle uniform pressure against the cylinder walls, without the aid of separate internal springs, and thus prevents the leakage of steam without introducing undue friction. If steam is found to pass to a serious extent, the cylinder cover should be removed at the first opportunity in order to readjust the packing of the piston. In the former case, when the packing consists of segments pressed outwards by a number of springs, the junk ring which holds these parts together must first be removed, so as to expose the adjusting screws by means of which the segments may be made to press more tightly against the cylinder walls. In doing so care must be taken to screw them up equally, so that the alignment of the piston may not be affected. The engine crank should then be blocked up to prevent it from moving, and steam admitted on the enclosed side of the piston. If steam still passes, the springs at these places should be screwed up until by repeated trials the springs are equally adjusted and there is no leakage. When adjusting screws are not provided the springs must be set individually by hand. In replacing the junk ring great care must be taken to secure all the nuts, as any part which may come adrift while running, especially at high speeds, is certain to prove disastrous. After replacing the cylinder cover the engine should first be turned through one complete revolution, to ensure everything being clear internally, and that the friction of the springs is not excessive. It does occasionally happen that tools are by accident left in the cylinder or lost in the ports. If the engine turns freely steam may then be turned on to test the tightness of the piston.

When the packing consists of split piston rings without springs, the piston should be withdrawn from the cylinder and the rings removed. By gently hammering the rings on the inside they may be expanded the required amount, so that when replaced they will again press against the cylinder walls. Care should be taken when hammering the rings to place the part on a block of wood or soft metal, to prevent the working surface from becoming indented. If the leak is not corrected at the first attempt the operation must be repeated until, little by little, the leakage is stopped. Care must be

taken that the springs do not press too tightly, otherwise the friction between the piston and cylinder will involve a considerable loss in power, and the wear of both will be serious. Absolute steam tightness should not be sought for if the spring pressure necessary is excessive. The piston should move sweetly in its cylinder without any very appreciable resistance. Under these circumstances the piston when at rest but under pressure passes a fine film of steam, but this ceases as soon as the engine commences to work.

Packing. This name is given to the substances used for filling the glands or stuffing boxes in which the moving parts of the engine work. The packing should have a certain plasticity, so that it may adapt itself as closely as possible around the rods working in the glands. Soft hemp is a very suitable material. Indiarubber, on the other hand, is not satisfactory. It becomes hard in contact with the steam, and the lubricating oil makes it rapidly deteriorate. To repack a stuffing box the old packing should be completely removed and the space thoroughly cleaned out. The hemp, twisted into a rope and well greased with tallow, should be wrapped round and round the rod and packed into the box until it is full. The cover gland should then be replaced and screwed up until about one-fifth of its length is forced into the box. Steam may then be turned on, and if any escapes the gland should be screwed up until the leakage is stopped. As in the case of the piston, the exact pressure required on the packing is best indicated by the amount of the leakage when the steam is turned on. Any haphazard tightening of the gland is bad and contrary to common sense, because the minimum pressure is desirable in order to reduce the friction on the rod. It is inconsistent to carefully grease the packing, to make it supple and frictionless, and then to compress it hard without reason. An excellent packing is formed of fine soft copper wire pleated and woven into ropes of square sections of various dimensions. The tightness of a joint or gland packed in this way depends upon the expansion of the copper when heated, so that it is not necessary to screw up the gland tightly, and thus the wearing of both the packing and the rod is reduced. Packing of this kind is very suitable for use with high-pressure steam, and lasts for several years, as the innumerable spaces formed by the crossing of the wire fibres readily retain the lubricating oil. There are many other forms of metallic packings, designed more particularly for use with high-temperature steam. In general they consist of split rings of soft antifriction metal pressed gently and uniformly around the working rod by other hard-metal spring rings.

Every care should be taken in packing the glands of an engine. Unimportant as they may appear, they are nevertheless very essential parts, and, if not properly adjusted, may lead to very severe accidents. If the piston gland is screwed up too tightly the piston rod may be fractured, or the engine may be suddenly brought to a stop, causing almost inevitably the breakage of some part of the machinery or of the shafting. It is most important, therefore, that the attendant should examine frequently the packings, and renew them regularly without waiting until they become hard and burned. Old packing should not in any case be used. The old material should all be removed, new stuff inserted, and the gland screwed up as required until the escape of steam just ceases.

Lubrication.—All the moving parts of an engine require to be effectively lubricated to reduce the friction, and thus to prevent the parts from becoming overheated and ultimately seizing. The lubricant may be either solid or fluid. Solid oils, such as hard grease or tallow, are generally used for the hottest parts of the engine, the cylinder and slide-valve boxes, and oil for the colder external parts. A volume would

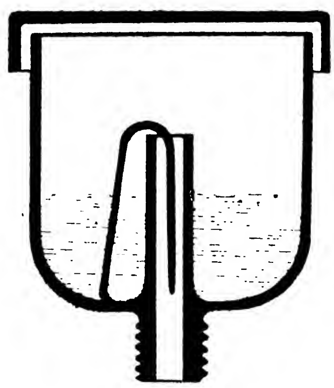


Fig. 93.—Syphon Lubricator

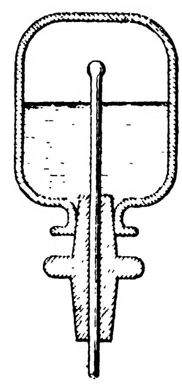


Fig. 94. Needle Lubricator

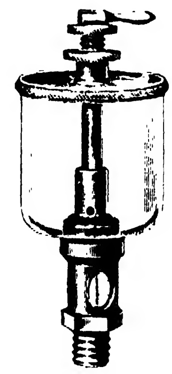


Fig. 95. Lubricator with Regulator and Sight Feed

be required to describe in detail the innumerable designs of lubricators that are in common use. A few distinctive types are shown in the illustrations. Fig. 93 consists of a glass oil vessel with a central tube rising above the level of the oil and passing down through the cover of the bearing to the rotating shaft. A few threads of wick are held together by a piece of twisted wire suspended in the tube, with the upper end hanging over into the oil. In this way a small and constant flow of oil is supplied to the bearing by the capillarity of the wick. When the engine is not running, the wick can be raised out of the tube and the flow of oil stopped. By the use of glass for the oil vessel the danger of the cup being allowed to run dry is obviated. A somewhat similar arrangement is shown in fig. 94, where the large tube and wick are replaced by a small-diameter tube containing a needle, the lower end of which bears on the moving part to be lubricated. The vibration of the needle induces a steady flow of oil down the small space between it and the tube. In fig. 95 the supply is controlled as desired by means of the handle at the top, which opens or closes the exit. Where oil requires to be admitted to a chamber under pressure, such as the cylinder, the type shown in fig. 96 is often employed. It may be also used when it is desired to supply a definite quantity of oil at intervals. When the lower tap is closed and the upper opened, the vessel may be filled, and then, on closing the upper tap and opening the lower, the contents will flow into the cylinder by gravity.

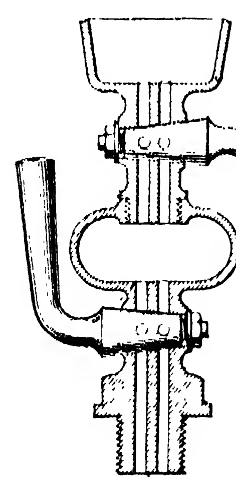


Fig. 96 Grease Cup

Sometimes it is necessary to force the oil into the bearings under considerable pressure. A type of pump commonly used is shown in fig. 97. It consists

simply of a cylinder containing oil, which is forced out to the bearings by the steady downward movement of the piston or plunger. The piston is advanced a definite small amount by means of a worm and wheel and a ratchet arm moved up and down by the engine. At the top a handle is also fitted to the plunger, so that an extra supply of oil may be forced out by hand when desired. When solid oil is used as a lubricant a form of cup shown in fig. 98 is often employed. The solid oil is placed in the cup, and forced out through the supply pipe by screwing down the cover as required.

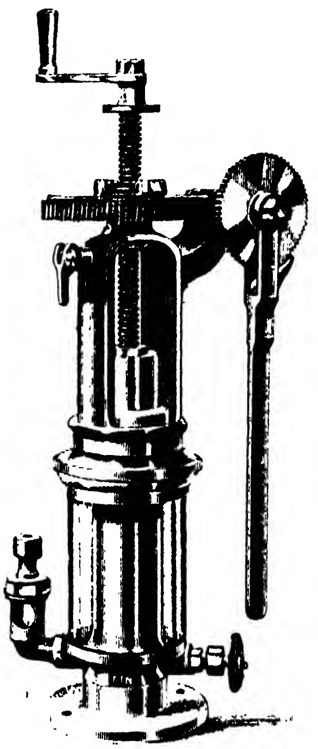


Fig. 97.—Mechanical Piston Lubricator

For the supply of oil to the cylinders automatic sight-feed lubricators are commonly adopted. Their action depends upon the condensation of a small quantity of steam which collects in the reservoir and forces out the oil drop by drop.

It is not always convenient or possible, owing to the complication of some engines, to fit separate lubricators to each moving part. In such cases it is easier to arrange one oil reservoir with separate pipes running to each bearing and joint (fig. 99). Frequently the reservoir is hermetically closed and fitted with an oil-gauge glass or other means of observing the level of the contents. In this way the flow is rendered more constant. By the use of this system of oil reservoir a considerable economy is effected. One man may easily attend to the lubrication of two or more large engines, while otherwise, when hand greasing is adopted, a man is required for each engine of any considerable size. The waste oil, too, may be more readily collected and filtered for use again, thus reducing the oil costs, which are always

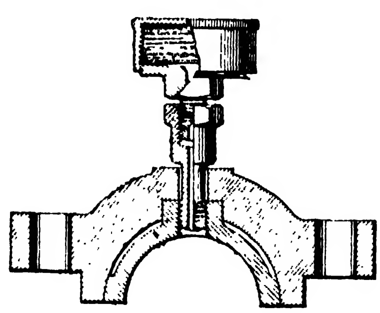


Fig. 98.—Stauffer Lubricator fitted to Bearing Cup

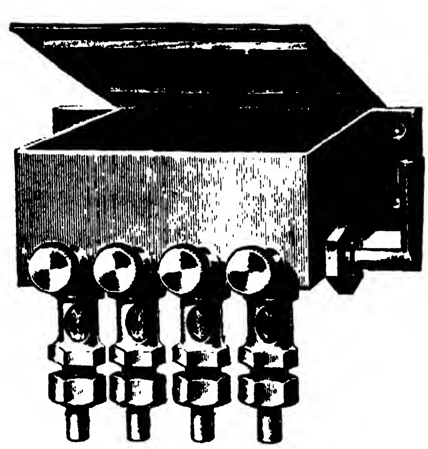


Fig. 99.—Oil Distributor with Sight Feeds

considerable. When open tank reservoirs are used care must be taken to exclude water, which, in certain situations, very readily finds its way into them. To outward appearance the box may be full of oil, while in reality there is only a thin layer on the surface of water. The finger should be dipped into the reservoir to test the quality of the contents.

The system of forced lubrication introduced by Messrs. Belliss & Morcom is now very generally used in high-speed engines. The oil is forced by a special valveless pump through all the bearings and moving parts at a considerable pressure, varying from 5 to 25 lb. Splash lubrication is also frequently used for high-speed engine work. The moving parts are completely enclosed, with the base of the engine arranged as a tank containing oil up to the level of the main shaft. As the cranks revolve, the oil is splashed over all the parts, thus thoroughly drenching them. In addition, small pipes are led from the crank heads to the upper ends of the connecting rods, or small channels are formed in the rod itself, so that each time the head plunges into the oil tank a supply is forced upwards to the upper joints.

Regarding the oiling of the cylinder, it must be noted that, although in certain cases this must be done regularly and thoroughly, in other cases it is not necessary, and may even be objectionable, as when the steam is wet. When the steam used is very dry, or superheated, or when the piston is fitted with bronze rings, lubrication is necessary. The need of oil may be readily detected by the grinding sound made by the piston as it moves. An increase of speed when oil is admitted to the cylinder is also a sign that lubrication is necessary there. The quantity to be used is a matter to be determined by experience. It should always be the smallest possible amount. As far as possible the use of grease as a cylinder lubricant should be avoided. Very often it is of inferior quality, and, especially so when it tends to form, with the dirt carried over by the steam into the cylinder, a paste, which gathers about the piston, corrodes the metal, and prevents the piston rings and springs from acting properly.

Belt Transmission. — Belts are most generally employed for transmitting the driving power of the engine to the shafting or directly to the machine to be worked. They generally consist of long continuous bands of leather pieced together and jointed at their ends, either by thongs of raw hide, or rivets, or wire stitching. To obtain the best results, the width of the belt should be about nine-tenths the breadth of the pulley, and the section should be sufficiently great to prevent the tension per inch of width, with a thickness of $\frac{1}{4}$ in., from exceeding 50 lb. Twenty-five pounds tension ensures a long life. A greater tension up to as high as 90 lb. may be applied, but the life of the belt will be thereby decreased. The surface of the pulley plays an important part in the running of the belt. To ensure the belt running centrally upon it the pulley face is turned convex. This convexity should never exceed $\frac{5}{32}$ in., whatever the breadth of the pulley. The surface should be continuous, especially at the crown of the face. An almost invisible ridge there has been known to make the belt run off the pulley. Broad belts slip more than narrow belts. This is due largely to the presence between the belt and the pulley of a layer of air, which in narrow belts is more readily expelled. When the thickness of a belt is considerable, the fibres are repeatedly and seriously strained as the belt passes round the pulleys. This is due to the difference in the lengths of the paths of the inner and outer belt-surfaces.

A similar straining effect takes place between the edge of a flat belt and the middle. This is due to the convexity of the pulley faces. Flexible link belts, shaped to the pulley,

overcome this difficulty, and transmit 25 per cent more power when run at high speeds. Laminated belts may also be shaped to the pulley. Belts of this character, formed of layers of material stitched together, should not be run on pulleys of less than 3 ft. diameter, in order to avoid rapid wear. Leather belts should not be run on their flesh sides. To secure quiet running, the joint of the belt must be flexible and not too thick. There are many kinds of belt joints, but the commonest method is to overlap the ends, after paring them down, and then to stitch them together with thongs. For very large belts copper rivets or screws and flat clamps are necessary to carry the drive. Light quick-running belts are best jointed with interlaced-wire hinges, which do not require the ends of the belt to be overlapped at all.

A new dry belt may slip and lose a considerable proportion of the driving power. To make the belt grip, a little powdered resin mixed with animal oil may be rubbed on the surface. If the loss is due to slackness, a piece must be cut out and the ends rejoined, but care must be taken that the tension is not excessive. Too tight a belt puts a severe strain upon the journals and the shafting. Sometimes a jockey pulley is fitted so as to press upon the slack side of the belt, thus obviating the necessity for frequent rejointing of the belt. A considerable loss of power often results from the belt being too tightly stretched. In many factories there is a tendency to exaggerate the necessary size and tension of the belts for a given power, with the intention of reducing slipping and of preventing excessive sagging when the length of the drive passes certain limits. To obviate this loss of power it is advisable to carefully proportion the size and tension of the belt to suit the actual maximum power to be transmitted.

Belts made entirely of leather generally give satisfaction in proportion to their higher price. Other materials are, however, well suited to particular kinds of drives.

Vulcanized rubber or gutta percha with interwoven canvas is often used, but belts of this kind do not run well in damp situations. They should not be run crossed, as the edges rapidly fray when rubbing past one another. Balata belts of chamois hair and of cotton are very generally used, and especially where there is much moisture. Fibrous belts seem to absorb the moisture and become tighter, while rubber belts, on the other hand, slip when water is present. A large rubber belt which is too heavy to remove by hand may be readily shifted by throwing a jet of water on its contact side. To reverse the action, if sawdust is thrown on the surface the water will be absorbed and the belt made to again grip the pulleys.

Belt dressings are frequently employed to keep the surfaces in good condition and prevent them from breaking up. The best and simplest dressing is common lard or a pasty mixture of animal fat in fish oil. A mixture of graphite, soap, and treacle is also satisfactory. On no account should mineral oil be used, particularly with leather belts, the fibres of which become very brittle when so treated. Castor oil is also bad. Its penetrating powers are too severe, and the leather fibres rot away. Fish oils and animal fats should alone be used.

Erection.—As so much depends upon the careful erection of an engine the work should only be entrusted to a skilful mechanic, preferably one who has been engaged in the manufacture of the particular kind of engine. Engine builders of any standing

erect all their engines on their own test plate at the works, and test them on full and low loads. This ensures that the engine will work without any fitting of parts when erected finally by the purchaser, provided the parts are properly aligned and adjusted by a competent man.

Steam Joints.—To prevent the steam from escaping at the joints of the engine, some soft jointing material must be used between the surfaces when assembling the parts. Generally hemp coated with red lead is employed, but often other materials are used. A good metallic joint is formed by using soft copper wire, especially where the temperature is sufficiently high to cause the copper to expand. Rust joints are formed by mixing iron filings with some oxidizing material, such as sal ammoniac. When mixed to a paste it may be spread over the parts or forced into the joint, where it hardens to a very durable cement. Sheets of cotton or asbestos with rubber are also used. Whatever the material used care should be taken to screw up the holding bolts equally, otherwise the flange may break when the hot steam is admitted, if not while screwing up.

Adjustment of the Valve.—To ensure good working of the engine, the steam-admission valve requires to be carefully set relatively to the position of the piston and the steam ports. Any faulty setting will give trouble and affect the efficiency to a serious extent. When the admission and exhaust valves are separately controlled, as in the Corliss gear, their relative adjustment can readily be effected. In the case, however, of the common **D** slide valve, controlling both admission and exhaust simultaneously, there is not so much latitude.

Defects due to Errors in Erection.—Any defective alignment of the main parts of the engine will result in excessive heating and knocking of the moving parts. The errors most likely to occur, unless carefully attended to, are enumerated below.

The shaft may not be level.

The shaft may not lie along the axis of the engine.

The hole in the piston cross head which takes the connecting-rod pin may not be bored square with the piston-rod hole.

The shaft may be displaced sideways in the direction of its length.

The piston rod may not be guided exactly in the axis of the cylinder.

The crank pin may not be parallel to the axis of the shaft.

Before accepting an engine from the erector it should be examined for these defects, and from time to time tests should be made with special appliances, to detect any want of alignment that may have developed. Any such defects should be noted and remedied at the first more-prolonged stoppage.

Care of the Bearings.—More constant attention is required to keep the bearings in good working order than is necessary in the case of any of the other engine parts, as they are subjected to continual shock and have to carry the whole load on the engine. Generally the material used for the bushes is bronze or hard brass, with an inner soft lining of white metal or other antifriction metal. In the case of high-speed engines the use of soft metal is inadmissible. Brass is not so durable as

gun metal, but it holds the oil well and is considerably cheaper. The cover of the bearing can be screwed down to suit the load and the speed. It is fitted with a lubricator, which supplies the oil to grooves cut in the faces of the bronze bushes. Bushes of almond wood are cheaper and hold the oil well, but they corrode the metal shafts to a slight extent. For this reason they should only be used for rotating shafts. If the shaft merely oscillates, the corrosion tends to make it become oval. Service-tree wood is equally good. Materials harder than the shaft itself may also be used, such, for example, as steel, case hardened or tempered. Two different metals always run better together than two metals of the same kind. Further, the softer material should be used for the part that can be the more readily replaced, generally the bushes of the bearing. Spare bushes should be kept with the halves soldered together until required. Their external dimension should be left about $\frac{1}{20}$ in. large, so that they may be fitted to the pedestal portion of the bearing, which may be somewhat worn. And for the same reason they should be bored out sufficiently small to allow of fitting to the worn journal of the shaft. Before fitting the bush it should be turned or planed true with the bore. A well-adjusted bush should fit the pedestal or plummer block without any play and yet without being in any way strained, and the oil channels should be amply large for the oil supply, otherwise the bearings will heat and give continual trouble. If the journal has become heated, and has seized to a slight extent, the roughened surfaces should be smoothed down with emery. The brasses also should be retouched with the file or scraper to remove the irregularities. Before replacing the bush both the brasses and the journal should be most carefully cleaned, to remove all grit and emery, and the surfaces coated with oil, which may be applied either by the thumb or with a piece of clean rag. After the cap of the bearing has been replaced the oil cups should be refilled. Only by taking every precaution to keep grit out of the journal, and by ensuring a steady supply of the lubricant, can trouble be obviated. If the journal has seized badly, and the surfaces are much torn, the damage should at once be repaired. When possible the journal should be returned in the lathe, as little satisfaction can be expected from any dressing with the file. The supply of oil should always be abundant without being excessive. Above all, the quality should be the best obtainable. Cheap oils are in the end more expensive than the dearer qualities, when the quantity used and the wear of the bearings, and the extra friction are considered. Contrary, perhaps, to expectation, a new bearing requires much more constant attention than an old one. Until the surfaces wear themselves to a true fit, and the roughnesses become smoothed down, the bearing will tend to heat up unless well oiled and attended to.

Speed Regulation.—Some method of automatically controlling the speed of the engine is essential, especially when the load is of a fluctuating character, and, even when the load is steady, variations of the steam pressure make a governor necessary.

Flywheels are fitted to allow the engine to overcome a sudden increase of the external resistance, as in the case of rolling mills, where the engine for a period runs idle at an increasing speed, storing energy in the flywheel to overcome the sudden load when the hot iron is drawn into the rolls. This is an extreme case which demands very special treatment. Most slow-running engines require flywheels to steady their

running, either by reason of variations in the effort of the engine or of the work to be done by it. When the speed of the engine is high a correspondingly lighter wheel is required. In the case of large engines for driving electrical generators, the flywheel action of the rotor is made use of. The size and weight and speed of the flywheel can only be determined by careful consideration of the nature of the load. Generally the diameter of the wheel is made about four to five times the length of the stroke. There is a limit to the diameter and the peripheral speed beyond which it is not safe to go. One hundred feet per second is sometimes adopted when the rim is in one continuous piece, but when the rim is made in two or more pieces, bolted together, the speed should not exceed 50 ft. per second.

Flywheels should not be made much too heavy for the work, in order to reduce as far as possible the friction losses. On the other hand, an ample factor of safety must be allowed. Small defects in the balance of the rim, especially sideways, throw heavy stresses on the spokes, and if a main journal should partially seize, or other stoppage occur, the stresses would become enormous. This has frequently been the cause of the bursting of flywheels, through the attendant attempting to cool a hot bearing with cold water. By cooling the bearing instead of the journal, the bearing may contract and seize upon the shaft, which has probably not contracted to the same extent.

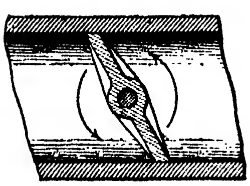


Fig. 100.—Common Throttle Valve

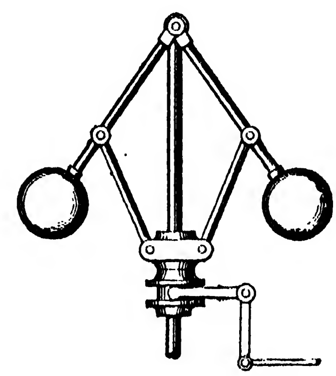


Fig. 101.—Watt's Centrifugal Governor

Governors are fitted to regulate the speed by controlling the supply of steam. The steam control may be effected in two ways, either by partially cutting off or throttling the steam supply, or by altering the point of cut-off at the distribution valve. The former method involves a slight loss of efficiency, but for small engines its simplicity makes its adoption very general. In high-speed engines, even of large power, throttle valve governing is also much favoured, owing to the simplicity of the gear and the few moving parts required. Instead of the old type of butterfly throttle valve, fig. 100, piston valves or double-beat Cornish valves are used in all but the cheapest engines.

James Watt devised the centrifugal governor, shown in fig. 101. It consists of two heavy balls suspended by links from a central spindle, the whole being rotated by the engine. At a certain speed the centrifugal force moves the balls outwards and also upwards, as the balls are suspended by the links. The resistance to the upward motion is the component of the force of gravity, and until the centrifugal force is sufficient to overcome this and the friction of the joints, the balls will not rise. The governor should be adjusted so that it does not rise until the normal speed has been somewhat exceeded, otherwise the throttle will be moved and the full power of the engine will not be obtainable. As the speed fluctuates past the normal, the balls rise or fall correspondingly, raising or lowering the collar which engages with the valve lever end.

In practice it may be found that, owing to a wrong length of the pendulum arms, or of the separation of the balls, the governor acts too late or too early. Say, for example, the normal speed is 40 revolutions per minute, and the balls rise at 42. In such a case the arms are too short, and must be lengthened. Similarly, if the revolutions are 38 instead of 40, the arms must be shortened. Increased sensitiveness is obtained by crossing the pendulum arms, as shown in fig. 102. The paths of the balls are thus inclined to one another, giving an effect similar to that obtained when the balls are made to move in parabolic guides. Sensitiveness may also be obtained by increasing the effective weight of the balls without increasing their mass. The Porter governor, fig. 103, is of this type. The weight on the centre spindle is equivalent to increased weight in the balls, and does not affect the centrifugal forces. Instead of the centre weight, springs may be used, allowing of easier adjustment of the governor setting.

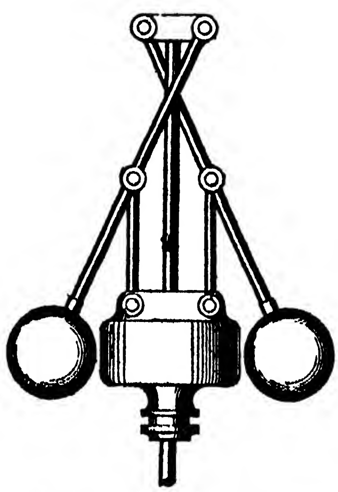


Fig. 102.—Crossed-Arm Centrifugal Governor

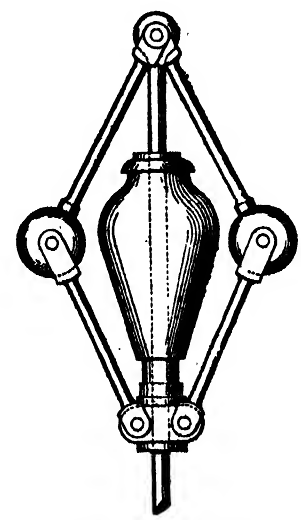


Fig. 103.—Porter Governor

Hunting of the governor takes place when the sensitiveness is too great for the engine, that is, the engine does not respond sufficiently quickly. In compound engines although the steam may be cut off at the high-pressure valve, there is still the steam of the cylinder and receiver to drive the low-pressure engine. Hunting may be remedied by making the governor more sluggish, either by increasing the friction or by fitting a dash pot.

In many types of engine the governor balls are fitted inside a small heavy flywheel on the main shaft. This arrangement is very suitable for varying the valve eccentric, and in this way controlling the point of cut-off at the cylinder.

The point of cut-off is varied in trip gears by the governor, which alters the position of the knife edge, causing them to release the valve rods earlier or later as the speed varies.

To Stop the Engine.—The boiler stop valve should first be closed, and then the condenser injection cock, if the engine is condensing. The cylinder blow-off cocks should be next opened, and lastly, the engine steam valve should be shut. It is necessary to close the boiler valve first, in order to prevent steam from being trapped and condensing in the piping. In winter time such water might freeze and lead to fracture of the steam mains. When stopping the engine it is safer to close the main steam valve as well as the engine valve. Two precautions are better than one, and there is the further assurance that an unauthorized person cannot, by opening the regulator, start the engine at an inopportune moment. Immediately the engine stops, the condenser injection cock should be closed, otherwise, in consequence of the vacuum

in the casing and the discharge pipe, the water would continue to be drawn in until it filled the interior and overflowed into the cylinders, where its presence might cause serious damage when the engine was restarted. The attendant should therefore on no account forget to close the injection cock.

All condensed water should be completely drained from the piping, cylinders, and jackets, particularly in winter time. When repairs are to be carried out, the parts should be dismounted before the engine cools down, otherwise it will be found very difficult to loosen the nuts without damaging them. Cleaning the parts can also be more readily done when warm, as the heat loosens the dirt and oil. If the engine is to remain unused for a considerable time, it is advisable to withdraw the piston and open out the valve chest, in order to thoroughly grease all the polished internal working parts to prevent oxidation. The external polished fittings should also be well greased to protect them.

ROTARY ENGINES

Much time and energy have been devoted to the development of engines capable of turning a driving shaft without the use of the intermediate parts essential to the conversion from reciprocating to circular motion, but an examination of the patent records shows that much of the labour has been wastefully expended in reinventing types that have been repeatedly tried without success.

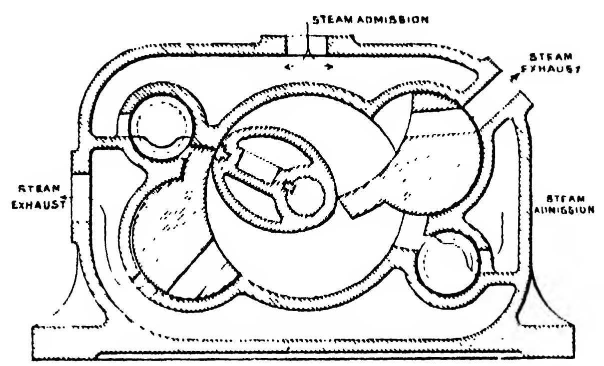


Fig. 104. Brown Rotary Engine

With the advent of electric lighting, the necessity for some type of rotary engine to directly drive the dynamo without the use of a belt caused engineers to devote much time to the problem, but although many designs were produced, the results were, almost without exception, disastrous. The development of high-speed reciprocating engines, and, later, of steam turbines, which satisfactorily meet the necessities of the electrical engineers, has left to the rotary engine an interest that is only historical.

Examples are shown of two types most generally favoured. The first belongs to the class of radial rotating pistons, in combination with moving pallets. Fig. 104 shows such an engine, as designed by Brown, a follower of Bramah. The small radial piston sweeps round the cylinder about a longitudinal axis, under the action of the steam upon the one side. Hinged pallets, which also act as steam-distributing valves, bear upon the radial piston and prevent the steam from escaping directly to the exhaust. It is largely the difficulty of making the contact of such pallets with the piston sufficiently steam-tight that has involved the failure of so many attempts. George Stephenson declared that the difficulty of making a line contact permanently steam-tight made the problem of the rotary engine insurmountable. So far the statement remains true.

The second type, illustrated in fig. 105, consists of a disc which constantly divides a steam chamber into two parts, one in communication with the boiler and the other with the exhaust. The motion of the disc under the pressure of the steam resembles that of a spinning top as it swings about its point. The pivot in this case is the ball at the centre of the disc, while the outer end of the disc spindle, moving in a circle, is coupled to the rim of a wheel on the shaft, which is thereby caused to rotate. A considerable number of these Bischopp disc engines were manufactured and put into practical service.

There is a third type of rotary engine, which has reappeared in endless designs. Such engines consist of cylindrical cams gearing with one another, and contained in a cylinder. As before, steam-tightness has to be obtained by means of pallets or sliding diaphragms, which give endless trouble, especially at high speeds. Many rotary engines are wrongly so called, in that they comprise reciprocating parts. An example of this type, resembling slightly the Bischopp disc engine, is illustrated in figs. 106 and 107. It is the West engine, which originated in America. Instead of the steam acting directly on the disc, as in the Bischopp engine, the driving force is applied around the disc edge by means of plungers working in cylinders, to which steam is supplied in rotation. A speed of 1000 revolutions per minute has been satisfactorily obtained in practice, but the engine is not now manufactured.

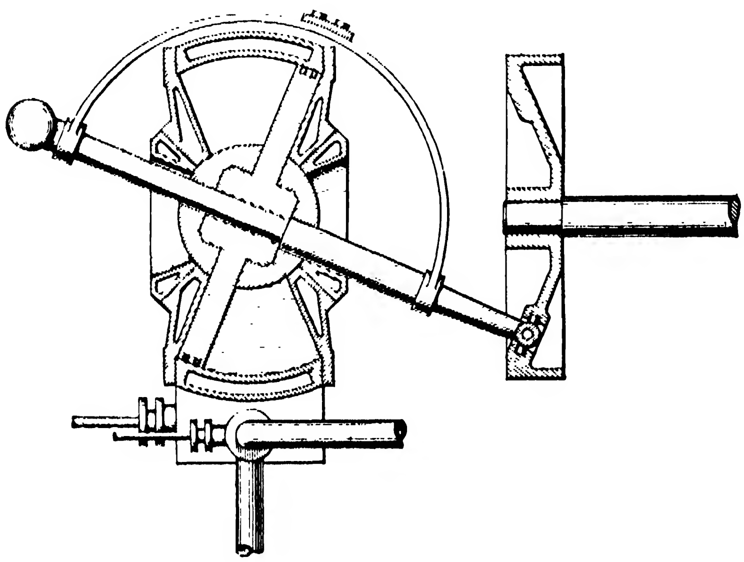
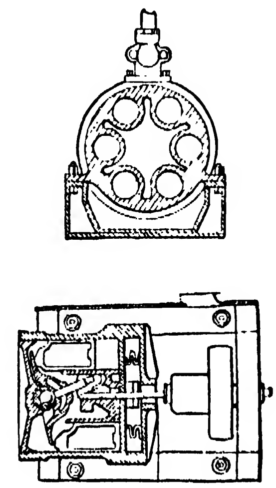


Fig. 105.—Bischopp Rotary Engine



Figs. 106, 107. - West Engine

THE STEAM TURBINE

Within a remarkably short period of time the whole aspect of steam engineering has been altered by the substitution of rotary for reciprocating means of utilizing the energy of steam. Although the advent of the economical turbine is of recent date, the idea of converting the energy of the steam directly into rotary motion is a very ancient one, that has occupied the constant attention of philosophers and engineers from the time 120 B.C. until the present day, when the perfection of engineering

STEAM ENGINE

SINGLE-CYLINDER ENGINE WITH SEPARATE INLET AND EXHAUST DROP VALVES

Index to the Principal Parts

1. Main Steam-inlet Pipe.
2. Steam Jacket.
3. Jacket Drain Cocks.
4. Main Stop Valve with Hand Wheel and Screwed Spindle.
5. Passages to Inlet Valves.
6. Inlet Valves.
7. Cylinder Working Space.
8. Piston.
9. Piston Rod.
10. Piston Cover and Gland.
11. Cylinder Cover.
12. Exhaust-water Drains.
13. Exhaust Passage behind the Exhaust Valves.
14. Exhaust Pipe.
15. Drain Cocks.
16. Cylinder Relief Valves.
17. Water Drain Pipe.
18. Cross Head.
19. Trunk with Cross-head Slides.
20. Connecting Rod.
21. Crank.
22. Driving Shaft.
23. Main Bearing close to the Crank.
24. Flywheel.
25. Pedestal Bearing between the Crank and Flywheel.

26, 27. Governor-shaft Bevel Gears.

28. Governor Shaft.

29–31. Governor-shaft Bearings.

32, 33. Governor-spindle Bevel Gears.

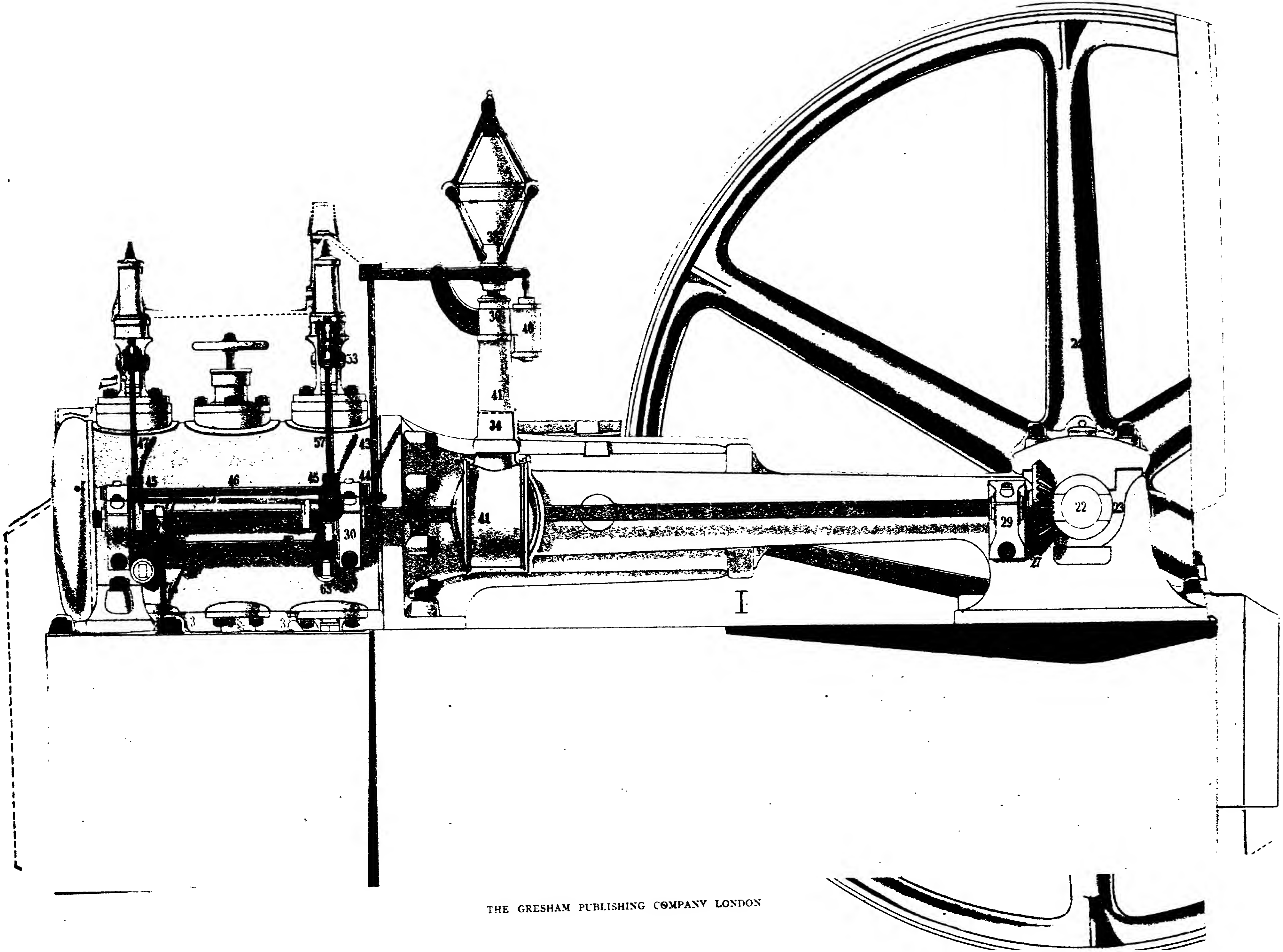
34. Governor Spindle.
35. Governor-spindle Foot Bearing.
36. Governor-spindle Upper Bearing.
37. Governor Balls.
38. Governor Sleeve.
39. Forked Governor Lever.
40. Cataract.
41. Governor Pedestal.
42. Governor Shaft Coupling.
43. Governor Valve Lever.

44, 45. Valve Cranks.

46. Driving Shaft for 47.
47. Valve Connecting Rods.
48. Admission Valve Box.
49. Valve Spindle.
50. Valve Bush.
51. Adjustable Valve Spring.
52. Double-armed Lever operating the Valve at Regular Intervals.
53. Spindle for 52.
54. End of Valve Spindle Lever.
55. Opposite End of Lever with Contact Plate.
56. Latch which Operates Valve Contact Plate on Descent of 57.
57. Valve Connecting Rod.
58. Latch coupled to 57.
59. Flat retaining Spring for Latch.
60. Trip Gear. The disengagement of the Latch is controlled by the governor.
61. Valve Rocking Arm.
62. Contact Roller.
63. Rocking-arm Spring.
64. Admission-valve Cam on Distribution Shaft.
65. Exhaust-valve Box.
66. Exhaust Valve.
67. Exhaust-valve Spindle.
68. Valve Head.
69. Adjustable Spiral Spring.

70, 71. Valve Levers.

72. Spindle of 70.
73. Stop on Spindle 67.
74. Exhaust-valve Connecting Link.
75. Lever Arm coupled to 74.
76. Contact Roller.
77. Exhaust-valve Cam on Distribution Shaft.
78. Rocking Shaft.
79. Cast-iron Foundation for Cylinder.
80. Foundation.
81. Indicator Connections on Cylinder.
82. Cylinder Lubricator Connection.



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processes and materials has made its realization practically possible. Hero of Alexandria invented, in the year 120 B.C. or thereby, a rotary engine or turbine, which is described in his *Pneumatica*, and at a much later date, in 1629, another type of steam wheel was invented by an Italian named Branca. These two turbines are of interest, as being the first examples which illustrate the principles underlying the present modern types, although it is probable that the principles embodied were not fully realized by the early inventors. Hero's turbine, illustrated in fig. 108, consists of a hollow globe carried upon trunnions, one of which serves for the admission of steam generated in the body of the support. From the globe project two nozzles, so arranged tangentially to the circle of rotation that the reaction of the escaping steam causes the globe to rotate. It is the principle of reaction introduced in the Hero engine that makes it of so much interest. In the Branca turbine, illustrated in fig. 109, the escaping steam impinges upon the vanes of a wheel, which rotates under the action of the impulse. In the example, which is an historical one, the wheel is shown doing useful work as a grinding mill.

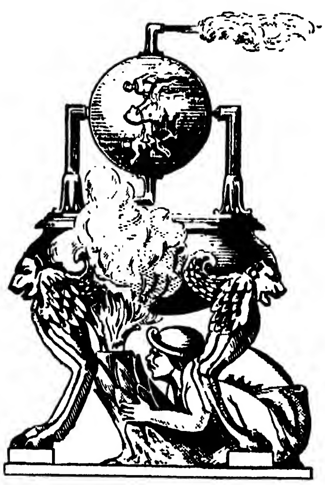

Fig. 108.—Hero's Engine

On the introduction of the reciprocating engine the development of the steam turbine practically ceased, owing to the difficulty of dealing with the enormous speeds involved.

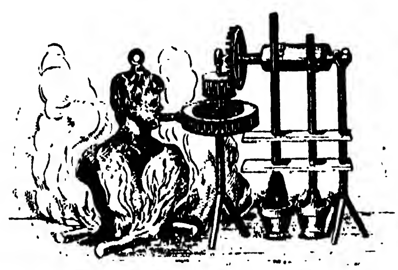

Fig. 109.—Branca's Engine

Heat engines of whatever kind do useful mechanical work at the expense of the heat contained in the working substance, and at the end of a stage the temperature must be less than at the beginning by an amount depending upon the mechanical work performed. Theoretically any gaseous substance could be employed in the heat engine, but in practice the choice is limited to substances that are easily obtainable and that can be brought to a convenient state. Steam, gas, oil-vapours, and air are all efficiently employed under different conditions in engines of the reciprocating type, but of these substances so far steam alone has been successfully applied in the turbine, although the development of the gas turbine in the near future is not improbable. Water turbines have for many years been employed for the useful conversion of the energy of water, but although to some extent the principles underlying both steam and water turbines are the same, there are essential differences which make a close comparison of little value. Steam is an elastic gas which may be compressed or expanded without limit, while water is practically incompressible, and the density of the steam is inconsiderable compared with that of water. In the water turbine the energy is generally in a kinetic form, which depends upon the motion of the mass of water as a whole and not upon the internal actions of the molecules, as in the case of steam and other gases, and it is in this respect that the two working substances so greatly

differ. Kinetic energy or energy of motion can be readily converted with very slight loss into mechanical work, and the first operation in a turbine is therefore to convert the potential energy of the working substance into a kinetic form, and then to convert the kinetic energy into the desired mechanical form. Upon the mass and the velocity depend the amount of the kinetic energy developed, and the velocity is proportional to the head, whether due to position or to pressure; thus the kinetic energy E of a mass m, moving with a velocity V, is $\frac{1}{2}\,m\,V^2$, and as V^2 equals twice the head h multiplied by the attraction of gravity g, the energy $E = m\,g\,h$, that is, the weight of the mass multiplied by the head. This equation, $E = \frac{1}{2}\,m\,V^2$, is true whatever the properties of the substance, but the energy may be due to a small mass moving at a high velocity or to a large mass at a lower speed, and for this reason the nature of the substance is of considerable importance. Owing to the comparatively great density of water the velocities involved in practice are moderate, whereas in the case of steam the small mass requires a great velocity, which in an impulse turbine, using steam at 280 lb. per square inch, and exhausting into a vacuum of 25 in., may amount to over 4000 ft. per second.

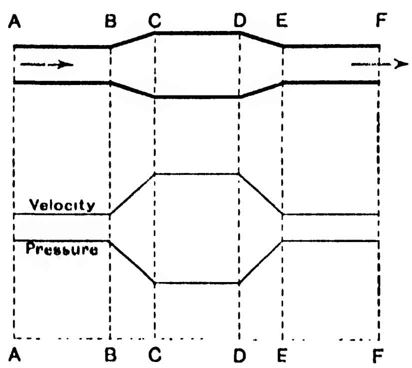

Fig. 110

When steam flows through a pipe the condition of the steam varies with the form of the pipe, as regards the proportions of its pressure and kinetic energy, as shown diagrammatically in fig. 110. From A to B the pipe is parallel, and in its flow through this portion the pressure and the velocity remain unaltered. At B the section increases, and as the steam expands its pressure falls and its velocity correspondingly increases, because, since the total energy is in no way altered, any decrease of the pressure or potential energy must mean a corresponding increase of the kinetic energy or energy of motion. This is indicated in the lower portion of the diagram, which shows the changes in the pressure and the velocity from section to section of the pipe. As the final section E F is equal to the section at A B, the condition of the steam at the end, so far as its temperature pressure and velocity are concerned, will be unaltered, provided no work has been done or that no energy has been dissipated in the process. If a portion of the kinetic energy generated by the expansion through B C be utilized in producing mechanical work, the final temperature pressure and velocity will all be reduced in proportion to the amount of the energy absorbed in doing the work. In steam turbines the pressure energy of the steam is converted, by expansion in suitably formed nozzles or passages, into kinetic energy, which is then absorbed in rotating the wheels of the turbine. A classification of the turbine may be based upon the manner of converting the heat energy into kinetic energy, and of then absorbing it in doing work, and the various well-known types are thus distinguished apart from the differences in their mechanical details. In the first class may be grouped those turbines in which practically the whole energy of the steam is converted at one operation into the kinetic form by suitable expansion in a nozzle, so that the moving wheels of the turbine serve only

for the absorption of the energy of motion and not for its production. When the range between the initial and the final pressures of the steam is great, the velocity generated is very considerable, and to reduce it the expansion in the second class of turbines is effected in several stages. During the first stage a portion only of the pressure energy is converted into the kinetic form and then absorbed, and in the succeeding stages the remainder of the energy is converted and absorbed, by definite amounts in each of the stages. This second system is equivalent to a series of two or more turbines of the first class, in each of which the fall of pressure, and therefore the velocity, is of a more moderate amount. To the third class belong those turbines in which the two operations, of expanding the steam and of absorbing the kinetic energy thus produced, take place to some extent simultaneously in the passages of the moving wheels. There are no turbines actually manufactured, in which the whole of the expansion is done in the wheel passages or vanes, which transform it into mechanical work; but such a system is theoretically possible, although it has not been developed. A combination of the two systems has been adopted in the Parsons turbine, in which the steam is expanded in a great number of stages, consisting of alternate fixed expanding vanes and of rotating vanes, in which kinetic energy is also generated simultaneously with its absorption. It is customary to use the term "impulse" or "action" in describing such turbines as those of classes 1 and 2, in which the kinetic energy is only absorbed by the rotating portions, and to use the term "reaction" to denote the third system mentioned above. As the Parsons turbine combines both systems, it is commonly referred to as belonging to the "impulse-reaction" type. Any such classification is, however, more or less arbitrary, as the principles underlying the effects of impulse and of reaction are the same. For the purpose of description the turbines in general use will be considered under the headings enumerated above, namely, impulse, reaction, and mixed or impulse-reaction, rather than in any historical order.

As already indicated, the history of the turbine may be traced back as far as 120 B.C., but the practical introduction may be considered as dating from 1884, when the Hon. C. A. Parsons was granted his first patent for a turbine of the compound impulse-reaction type. Four years later, in 1888, Dr. G. de Laval introduced the impulse type, which has since been very successfully developed, and Mr. Curtis of America carried the idea still further by patenting, in 1896, the multicellular type, which was practically introduced in 1902. Variations of the above types, introducing details of some novelty, have been placed on the market by various makers within recent years, but of these only the Rateau turbine will be described here.

To the first and second groups, as classified above, belong such turbines as the de Laval, Rateau, Curtis, and Zoelly, while the Parsons turbine is the most important example of the mixed type. As already stated, no turbine of the purely reaction type is manufactured.

In 1882 Dr. G. de Laval introduced a simple turbine resembling the ancient Hero engine illustrated in fig. 108. It consisted of a tube bent into the form of the letter **S**, with the idea doubtless of reducing the losses due to shock at the turns, but the efficiency of the arrangement was not great, owing to the steam being ejected with

considerable velocity. It was originally devised for the direct driving of centrifugal cream separators, in which a very high speed is an essential feature. On account of its simplicity and compactness the arrangement is a very suitable one for the purpose for which it was designed, and many of these turbine separators are still in operation.

Following the application of the simple reaction wheel to the driving of separators, de Laval patented, in 1889 and in succeeding years, his impulse turbine, in conjunction with his system of expanding nozzles for converting the pressure energy of the steam into the kinetic form. If steam be passed through a nozzle of the form shown in fig. 111, the volume increases from the section B to the final section C, and, as a result, the pressure falls while the velocity increases, with a consequent conversion of the pressure energy into kinetic energy. By suitably proportioning the sections, the pressure may be reduced in the nozzle from that of the boiler down to the exhaust pressure, in which case the whole available energy of the steam is converted in the one expansion, and the pressure throughout the turbine wheel itself does not alter. As the steam leaves the nozzle it is made to impinge upon the curved vanes on the periphery of the turbine wheel, which rotates under the action of the impulsive force of the high-velocity steam jets. This is clearly shown in an ideal form in fig. 112, where four nozzles are shown acting upon different sections of the periphery, thus increasing the power obtainable from any particular size of wheel. Each nozzle in the actual machine is inclined to the wheel at an angle of about 20°, and the vanes are correspondingly arranged so that the steam may enter them without shock and loss of power when they move at the designed speed. For maximum efficiency the speed of the rotating vanes should be about one-half that of the velocity of the steam as it leaves the nozzle and enters the buckets, but in practice a smaller velocity is adopted, as, with high-pressure steam and a good vacuum, the velocity is inconveniently great. If, for example, the initial pressure were 280 lb. per inch square, and the back pressure, due to a vacuum of about 28 in., were 1 lb., the velocity of the steam after expansion in a suitable nozzle down to the exhaust pressure would be over 4000 ft. per second, and the corresponding speed of the wheel buckets would require to be about 1800 ft. per second, in order to obtain the full mechanical value from the machine. Any speed of revolution can be provided, while retaining the same peripheral speed, by suitably varying the diameter of

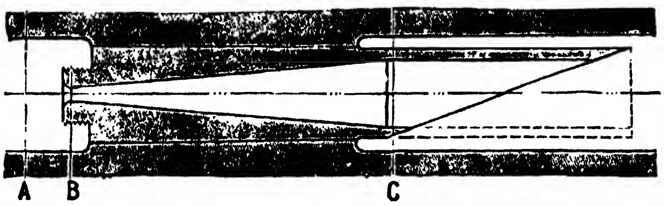

Fig 111.—De Laval Expansion Nozzle

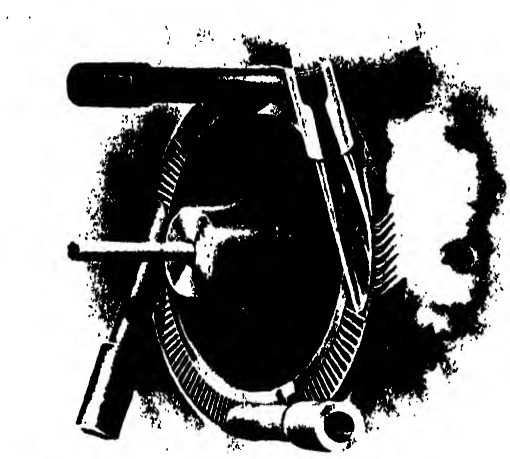

Fig. 112.—De Laval Steam-Turbine Wheel

the wheels, but there are constructional objections to an undue increase of the diameter, and, in the case of certain types of de Laval machines, the speed of revolution is reduced by means of gear wheels, as illustrated at H, in figs. 113 and 114. When the steam leaves

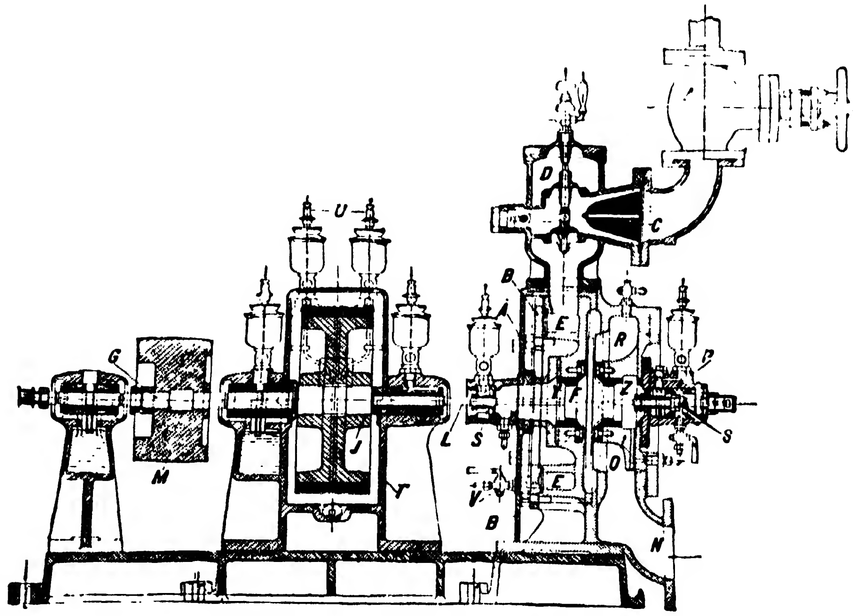

Fig. 113.—Sectional Elevation of De Laval Turbine

the nozzle and enters the wheel buckets its condition, as already explained, has undergone certain changes. All the energy obtainable from the expansion down to the exhaust pressure is in a kinetic form, and the pressure of the steam is that of the condenser, or of the atmosphere when no condenser is used, so that in the wheel itself there is

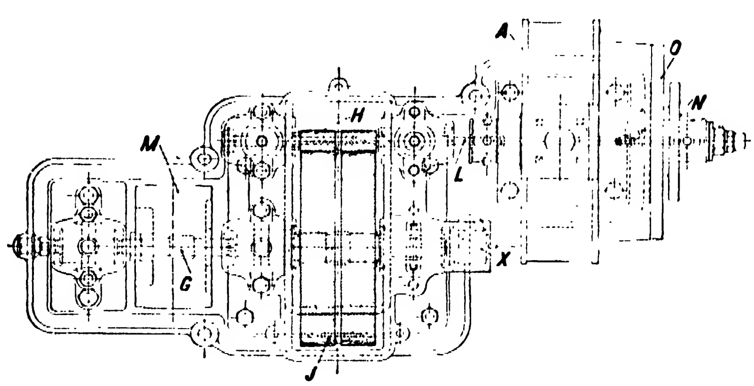

Fig. 114.—Plan of De Laval Turbine

no change of pressure. This condition is determined by the uniform section of the passages or vanes of the turbine wheel, which absorbs the kinetic energy without affecting the pressure. Fig. 115 shows the parallel arrangement of the vanes on the periphery of the wheel, and one of the expansion nozzles, with its controlling valve, which will be again referred to. An external view of a 225-b.h.p. turbine dynamo

set is given in fig. 116, but the sectional elevation and plan, figs. 113 and 114, illustrate a 20 h.p. type provided with a pulley for belt driving. Referring to the section, A is the main stop valve, which admits the high-pressure steam through the strainer, C, and the controlled throttle valve, D, to the annular steam chamber, E, from whence it passes

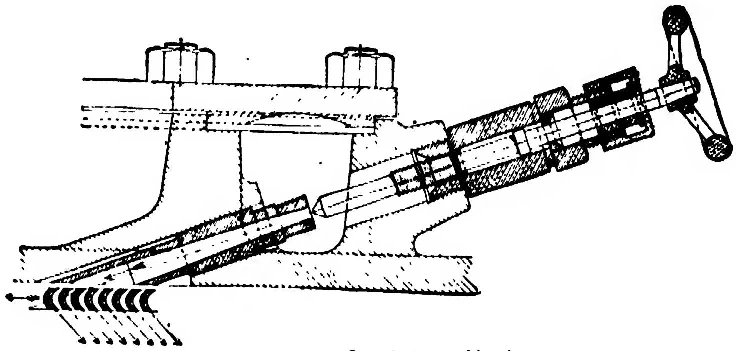

Fig. 115. De Laval Steam Nozzle

through the expansion nozzles and the turbine vanes into the exhaust passage, K and N. Several nozzles are placed around the wheel casing, as shown in fig. 116, and by opening or closing one or more of these the power may be varied as required, without seriously affecting the efficiency, even when working at only half load. When dealing with very high speeds, considerable trouble is experienced from vibration, unless the rotating

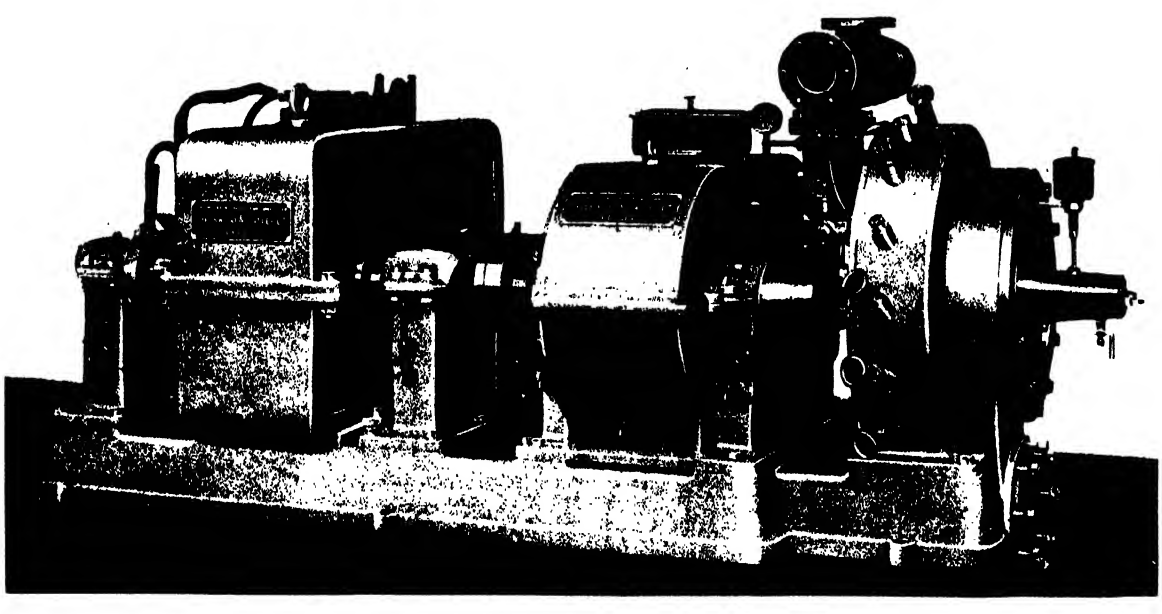

Fig. 116.—Steam Turbine-Dynamo, 225 B.H.P. Capacity, 150 Kilowatts

parts are very perfectly balanced. This difficulty is overcome in the de Laval turbine by making the wheel axle sufficiently long and slender to allow the wheel to rotate about a true axis through the centre of gravity, which may not lie in the axis of the spindle, owing to the practical difficulty of balancing the wheel to the required degree of accuracy. Up to a certain speed of rotation the vibration increases rapidly, but

beyond this point, termed the "critical speed", the wheel suddenly settles down and continues to run without vibration, due to the axle bending sufficiently to permit the wheel to rotate about its true dynamic centre. It is possible to use a small-diameter shaft, as the torques to be transmitted are small, owing to the high speed of rotation. Two arrangements of the wheel and the shaft are shown in figs. 117 and 118, the former being the system adopted for small-diameter wheels, and the latter that for large ones in which it is not permissible to weaken the centre of the wheel by boring it through to take the spindle. As shown in fig. 118, the flanged ends of the shaft are bolted into recesses turned in the wheel boss, thus preserving the continuity and strength of the wheel. In the figures are also shown sections of the vanes or buckets, and the method of dove-tailing them into the periphery of the wheel. An essential feature of the de Laval turbine is the flexible shaft, which is clearly shown in the sectional view, fig. 113. F is the wheel, with its bosses recessed to take the flanges

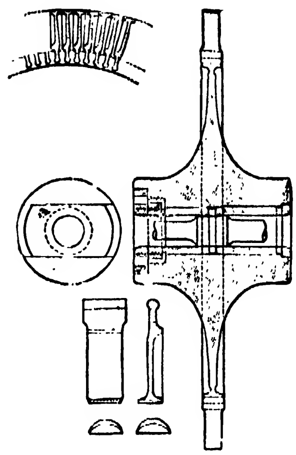

Fig. 117. Details of De Laval Wheel and Flexible Shaft

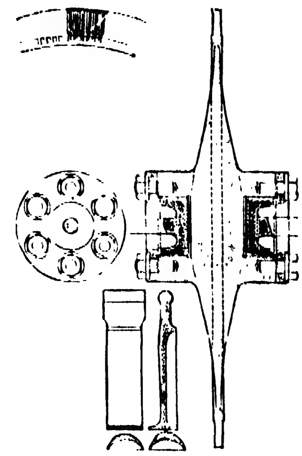

Fig. 118. De Laval Turbine Wheel with Solid Centre

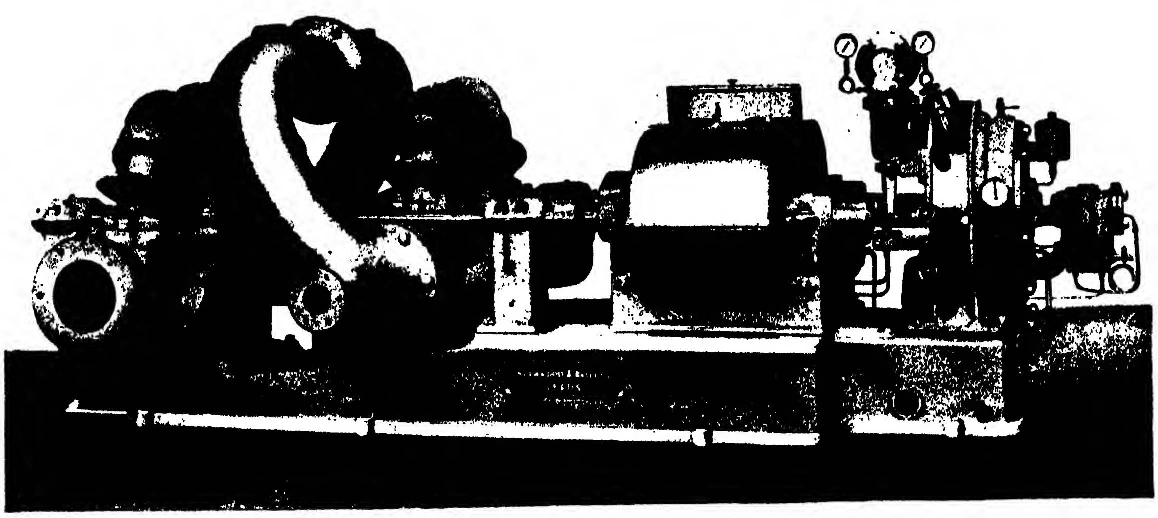

Fig. 119.—De Laval Turbine, 150 B.H.P., coupled to Pump. Capacity, 1400 Gallons per Minute

of the shaft L, which is borne in the bearings S S, placed at a considerable distance apart to give the required flexibility. For a turbine of 300-h.p. the shaft is made about $1\frac{5}{16}$ in. in diameter, and 1 in. in the case of a 150-h.p. turbine. As the normal speed of the wheel is too great for direct driving of ordinary machinery, it is customary to reduce it by means of double-helical gearing, which in some cases is duplicated, as

in fig. 116, and in others single, as in the detailed illustration, figs. 113 and 114. H is the double pinion on the turbine spindle, which gears with the large toothed wheel J, carried, together with the pulley M, upon the shaft G. It will be noted that this second shaft is of a larger diameter, to withstand the larger torque which results from the slower speed of rotation. In the turbo-dynamo set, fig. 116, the generator is duplicated, with an armature fixed upon each of the two shafts. This gives a convenient arrangement, as the two dynamos may be worked in series or in parallel or on a three-wire system. Another combination is illustrated in fig. 119, which shows a 150-b.h.p. turbine directly coupled to a Greenwood & Batley series pump having a capacity of 1400 gal. per minute under a pressure head of 240 ft.

A sensitive centrifugal governor, mounted horizontally upon the gear-wheel shaft, serves for the automatic regulation of the speed, which is effected by means of the double seated balanced steam valve D, fig. 113. Superheated steam may be used most effectively in steam turbines, as there are no internal moving parts that work in contact with one another; and in the case of the de Laval turbine there is the additional great advantage that the high-temperature steam is confined to the stationary nozzles and does not come in contact with the moving wheel, which only rotates in a chamber filled with low-temperature steam at the pressure of the exhaust. On either side of the wheel there exists the same pressure, and, as a result, there is no tendency for the steam to leak past; but to entirely prevent such a possibility, the vanes are extended radially beyond the outlets of the nozzles. It is also possible to provide large clearances between the fixed and moving portions, thus removing one of the most serious difficulties encountered in other types. Table I contains the results of

TABLE I. TESTS WITH A 30-H.P. STEAM TURBINE WORKING WITH SATURATED AND SUPERHEATED STEAM RESPECTIVELY

NON-CONDENSING

Steam Pressure: 7 atmospheres absolute = 88.2 lb.
Speed of Driving Shaft: 2000 revolutions per minute.
Speed of Turbine Wheel: 20,000 revolutions per minute.

		Half Load		Full Load.	
		Saturated Steam.	Superheated Steam.	Saturated Steam.	Superheated Steam.
Temperature of the Steam	Centigrade	164	460	164	509
	Fahrenheit	327	860	327	932
Power developed	Metrical b.h.p.	21.4	24.5	44.1	51.9
	English b.h.p.	21.1	24.2	43.5	51.2
Steam Consumption per b.h.p. per hour ...	Kilogrammes per Metrical b.h.p.	21.6	14.1	17.7	11.5
	Lbs. per English b.h.p. ...	48.3	31.5	39.6	25.7
Heat Consumption per Metrical b.h.p. per hour in Metrical Heat Units		14160	11270	11610	9390
Temperature of Exhaust Steam	Centigrad	100	309	100	343
	Fahrenheit	212	588	212	649

tests made upon a 30-h.p. de Laval turbine at half and full load, when using superheated steam and also saturated steam. From these tests it appears that increased superheating results in a reduced steam consumption, and also in a reduction of the heat consumed per horse power.

Losses in a steam turbine are due to one or more of three principal causes, namely, friction of the steam and condensed moisture upon the metal surfaces, leakage past the moving wheels, and partial eddy-current losses arising from shock and imperfections in the steam passages. So far as the de Laval turbine is concerned there is practically no loss due to leakage, as the pressure does not differ on the two sides of the turbine wheel, but it is subject to the other losses mentioned. Experiments have demonstrated the serious erosive effect of wet steam when moving at high velocities, and impinging upon even the hardest steel surfaces. Below a speed of 500 ft. per second the steam has only a slight wearing effect upon the drawn brass vanes, but above this speed the effects rapidly increase in proportion to the square of the velocities until, at a speed of about 4000 ft. per second, resulting from the expansion in a suitable nozzle from a pressure of 100 lb. down to a vacuum of 28 in., the hardest steel becomes rapidly worn under the impact of the particles of water. Although the steam actually leaves the expanding nozzle of the turbine at this high velocity, it impinges upon the buckets at a comparatively low speed, as the wheel rotates in the same direction, and the wear of the blades is in reality inconsiderable. Some loss of efficiency results from the formation of eddy currents at the entrance to the vanes, especially when the turbine wheel rotates at a speed other than that corresponding to the velocity of the steam, as is the case in the de Laval arrangement; but the losses from this cause are not so great as might be expected, owing to the slight reduction in the percentage of moisture which simultaneously takes place.

In 1896 Mr. Curtis obtained his first patent for the type of turbine which has been included above under the second class, and in 1902 it was placed upon the market by the General Electric Company, of America. So far as the action is concerned, the Curtis turbine comes between the de Laval and the Parsons type, which will be described later, but the arrangement and the details differ in many important respects. Steam is expanded in nozzles on the de Laval principle, but the expansion is not carried to the full extent in the first set. Generally four stages are adopted, that is, the steam is expanded to a certain extent, and the energy then absorbed in one stage, as in the de Laval type, and in the succeeding stages the remainder of the energy is transformed in the same way. By dividing the transformation over four stages the velocity of the turbine wheel is reduced, as the speed corresponds with the drop of pressure between the stages. Each stage consists of a ring of stationary nozzles, in which the steam is partially expanded, and of a rotating wheel, the buckets of which absorb the kinetic energy of the expanded steam. Fig. 120 shows diagrammatically the arrangement of the stationary and the moving vanes of the Curtis impulse type, and for comparison the arrangement of the guide vanes and moving vanes of a reaction turbine is also given in fig. 121. It will be seen that the passages between the moving vanes are not similar in the two cases, the section measured at right angles to the course of the steam being uniform in the case of the

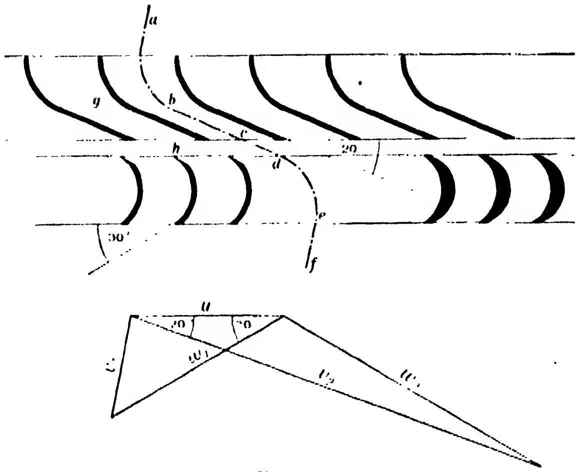

Fig. 120

reaction turbine. As the guide vanes serve the same purpose in both types, they have been drawn alike in the diagrams. A clearer idea of the action may be obtained by constructing a diagram of velocities, as in fig. 120. If the line *abc* represents the flow through the stationary guide, *cd* will be the path of the steam at the moment of leaving the vane; but as the wheel vanes are moving forward with a certain velocity, *cd* will not represent the direction of the flow relatively to the moving vanes, which the steam is about to enter. This relative velocity may be determined in direction and magnitude by compounding the velocity of the steam at the guide exit and the velocity of the wheel bucket. In the diagram, v_2 is drawn parallel to the guide vane at the exit, and it represents, since the guide is stationary, the velocity and direction of the steam relatively to the earth, u represents the velocity of the wheel, and the resultant w_2 therefore represents the direction and velocity of the steam relatively to the moving vanes, the edges of which must lie in the same direction to avoid all possible shock at the entrance of the steam to the buckets. The steam leaves

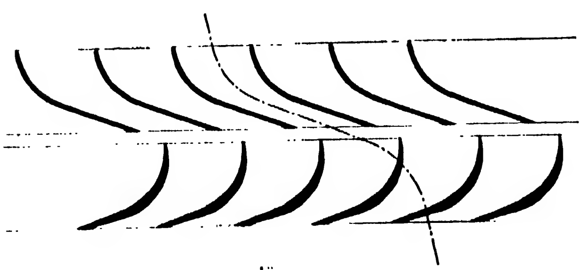

Fig. 121

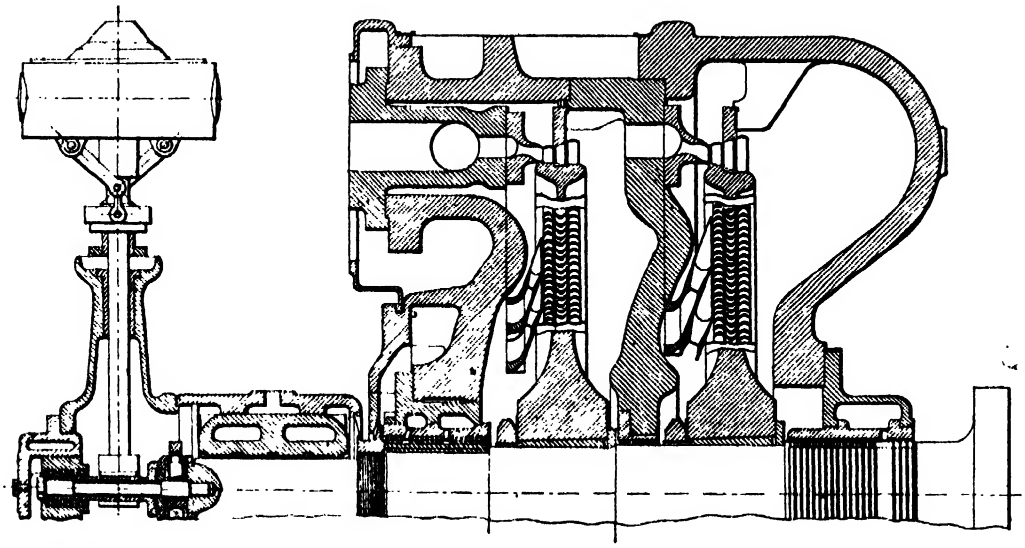

Fig. 122

the moving buckets tangentially, as represented by w_1, which is the velocity relatively to them, and this, compounded with the velocity u of the wheel, gives the resultant v_1,

which is the velocity of the steam relatively to the next set of fixed guide vanes, which as before must be arranged tangentially to avoid losses from shock at the admission. Two, and sometimes three, rows of vanes are carried upon the peripheries of the rotating wheels with intervening fixed guides, which merely serve to redirect the flow of the steam to the following ring without in any way changing the velocity or pressure. A certain loss of efficiency results from the use of several rings of buckets on each wheel, as the steam has more frequently to impinge upon the edges of the buckets, and the friction in the passages is also increased. This difficulty is also experienced in turbines of the Parsons type, but to a smaller extent. Fig. 122 shows the essential features of the Curtis turbine, as manufactured by the Allgemeine Elektricitäts Gesellschaft, of Berlin; but a radial section only is indicated. The high-pressure steam enters the first ring of expanding nozzles, and then passes through the moving wheel buckets, which in this particular example are arranged in two rings separated by a set of fixed guides. After passing through this first wheel the steam is further expanded in a second set of expanding nozzles, and the resulting kinetic energy is absorbed as before in the buckets of the second wheel. A turbo-generator set is illustrated in fig. 123, which shows in section the single-wheel type. There is in this example only one pressure stage, but the wheel has three velocity steps. For the sake of clearness the intermediate fixed guides are not indicated between the rings of moving. This represents the smallest type of turbo-generator manufactured by the Allgemeine Elektricitäts Gesellschaft, and the steam consumption aimed at is equivalent to that of corresponding small marine steam-generator sets. For powers up to 1000 kilowatts, and speeds of about 3000 revolutions per minute, two pressure stages, each with two velocity steps, are provided, but only one set of buckets is used on the second wheel when the vacuum is very low. This arrangement is illustrated in the sectional fig. 124,

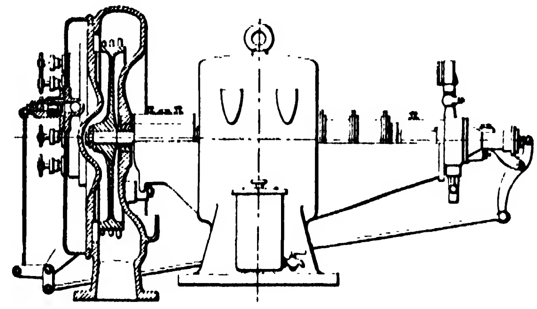

Fig. 123.—A.E.G.-Curtis Turbine, with One Pressure Stage and Three Velocity Steps

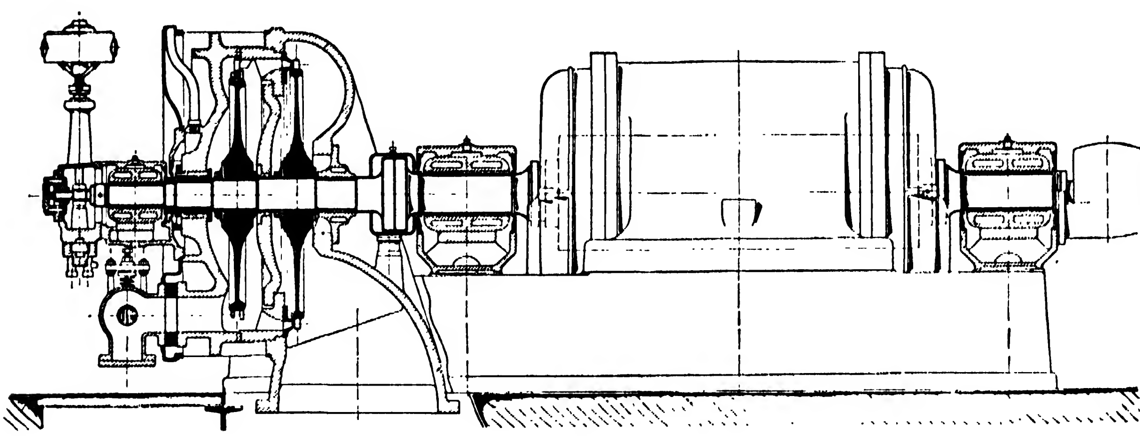

Fig. 124.—A E.G.-Curtis Turbine with Two Pressure Stages, the Second having One Velocity Step only

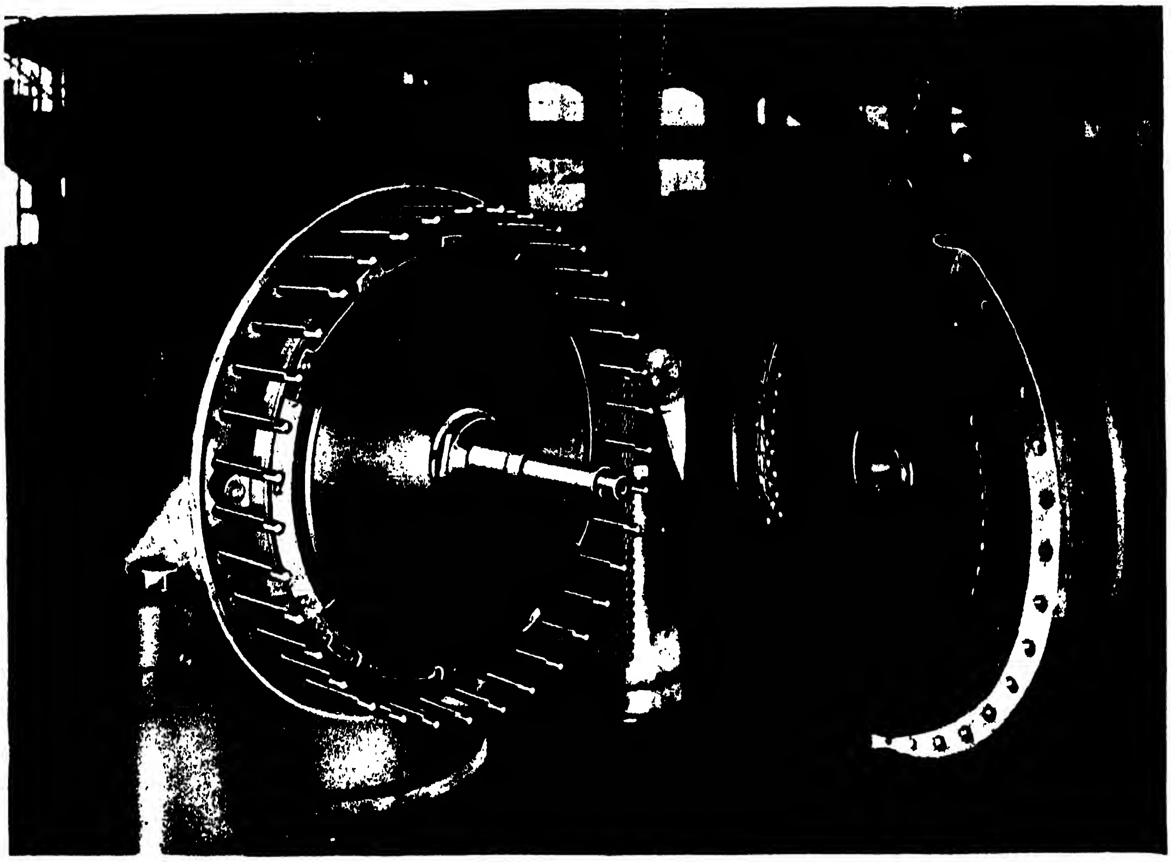

Fig. 125.—Allgemeine Elektricitäts-Gesellschaft Curtis Turbine: Front Cover removed

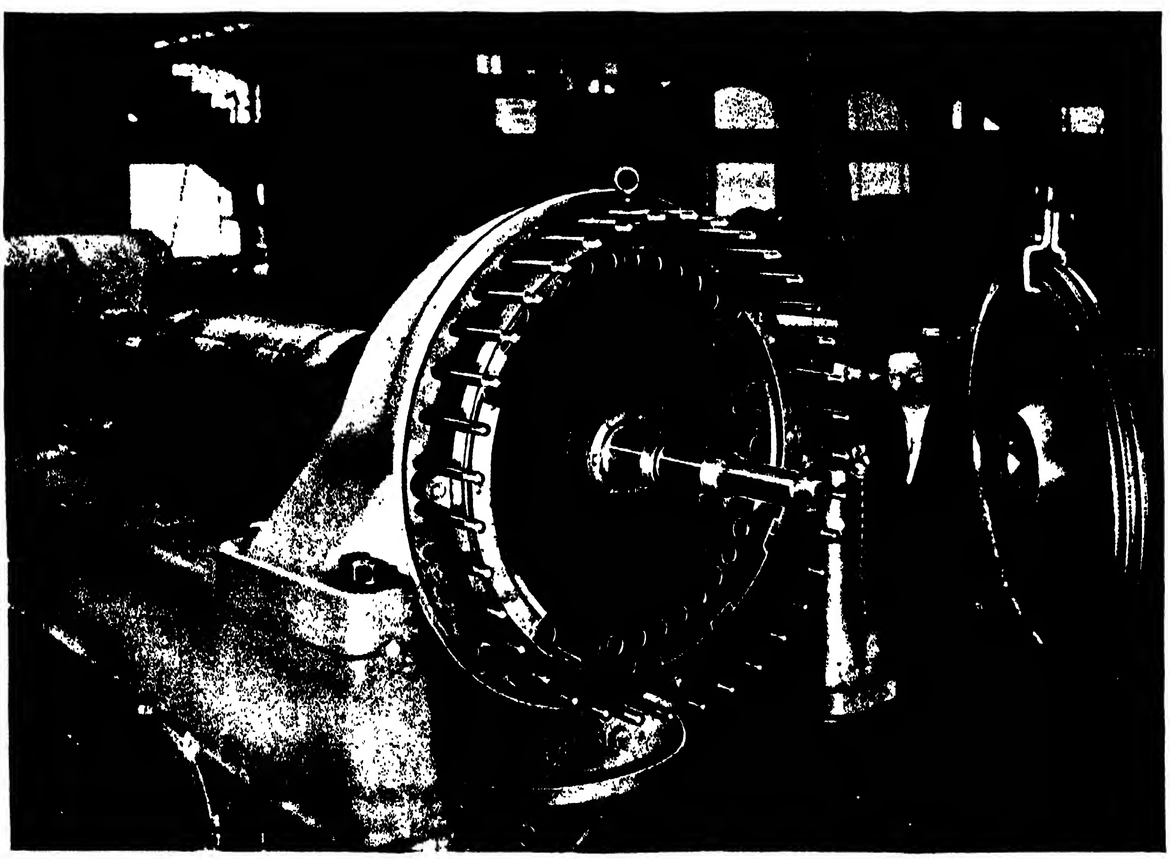

Fig. 126. First Stage Wheel removed

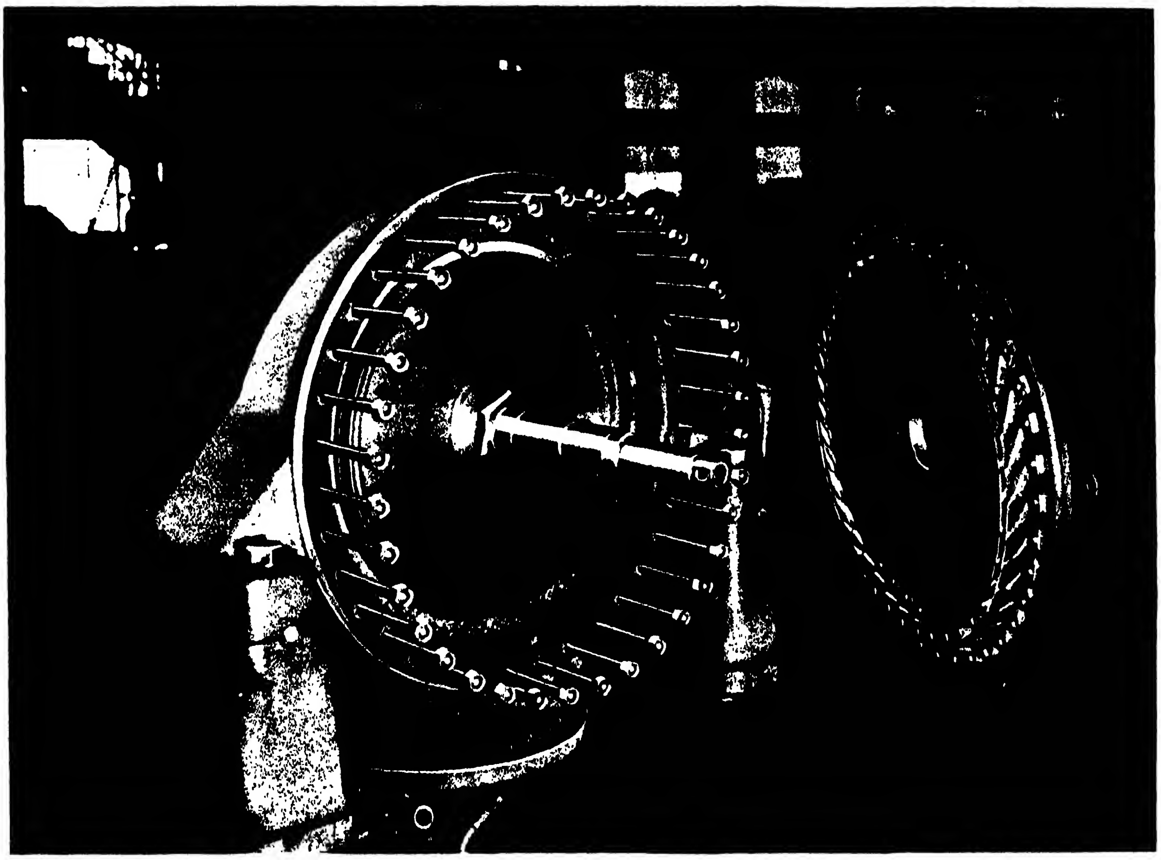

Fig. 127.—Second Stage Nozzle Diaphragm removed

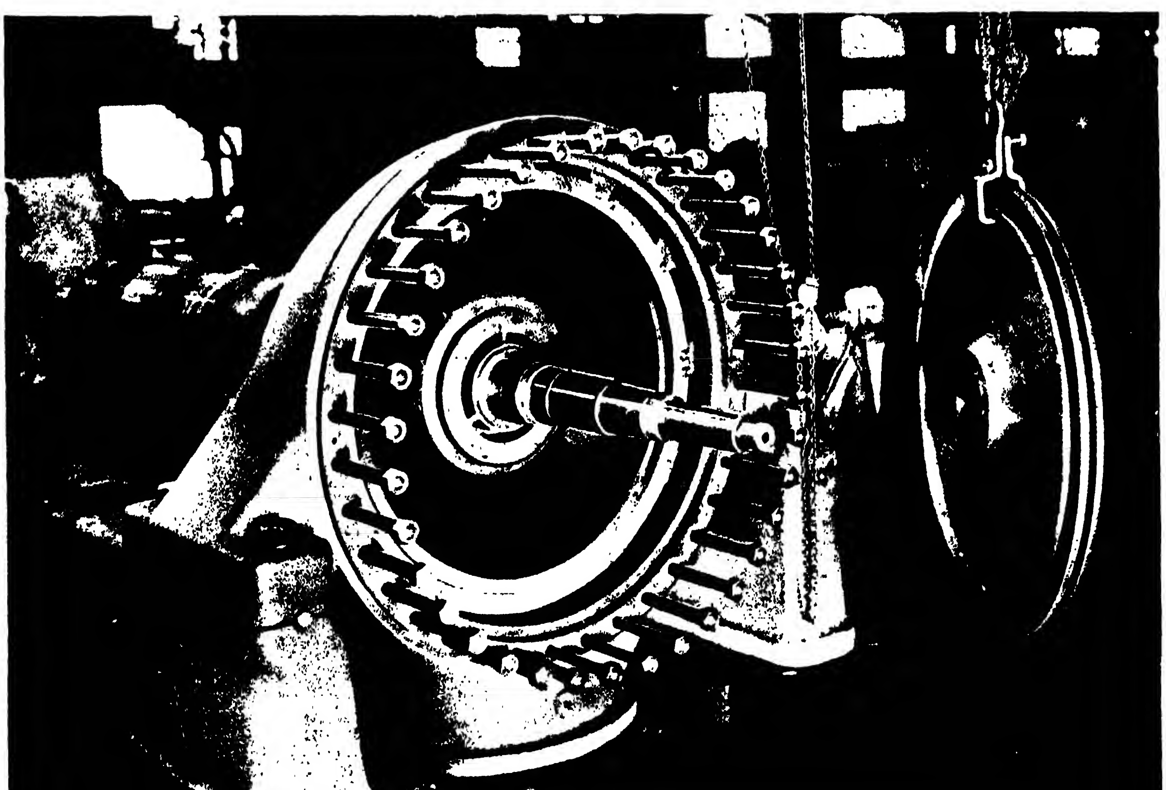

Fig. 128. Second Stage Wheel removed

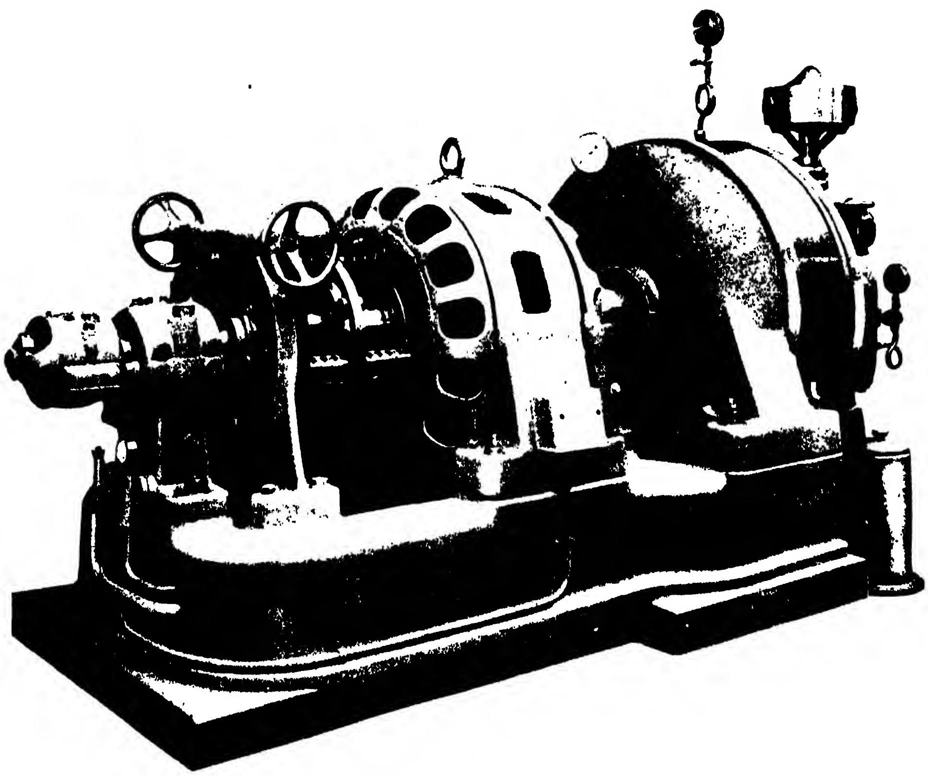

Fig. 129.—A.E.G.-Curtis Continuous-Current Turbo-Generator

and several views of the actual mechanism are given in figs. 125, 126, 127, and 128. In the first view the cover containing the steam expansion nozzles has been removed, to expose the first-stage wheel and ring of buckets. Nozzles are only provided around a portion

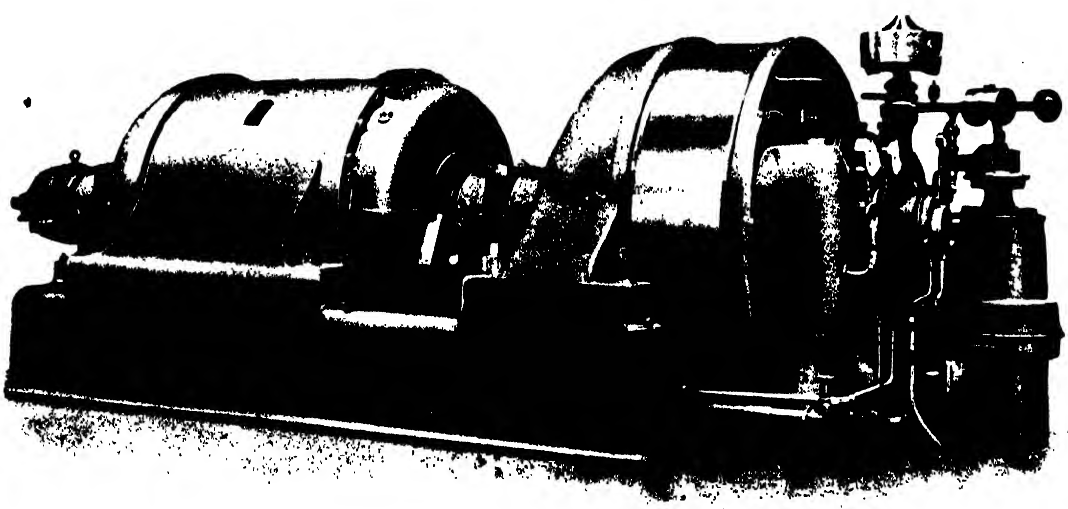

Fig. 130.—A.E.G.-Curtis Three-Phase Turbo-Generator

of the first-stage wheel, and the delivery ends of these are clearly indicated on the inner face of the cover. As the volume of the steam is much greater after the first expansion, it is necessary to provide nozzles around a greater portion of the second stage

guide, as shown in fig. 126. This view shows the first wheel removed, but two sections of the fixed guide ring, which separates the two rows of buckets on the wheel, have been replaced to indicate the position occupied by them. Fig. 127 shows the second-stage wheel exposed by the removal of the disc containing the second set of nozzles already referred to. These nozzles may be seen around the whole periphery. In the last view, fig. 128, the second wheel with its two rows of vanes is shown removed, but as before the ring of fixed guides has been replaced. After passing through this second wheel the steam is exhausted to the condenser through the large passage underneath the turbine casing. To illustrate the very compact nature of the design, two examples of typical turbo-generator sets, built by the Allgemeine Elektricitäts Gesell-

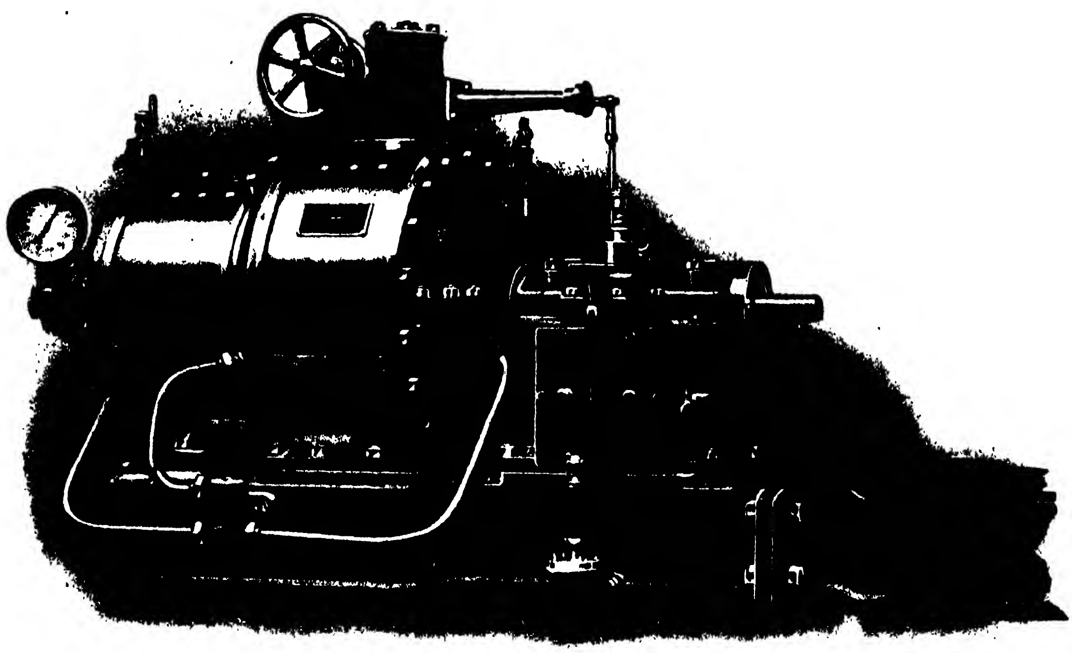

Fig. 131.—High-pressure Rateau Steam Turbine, 60 B.H.P., 5000 R.P.M.

schaft, are given in figs. 129 and 130. One of these, fig. 129, shows a 50-kilowatt continuous-current set, and the other, fig. 130, a turbine coupled direct to a 200-kilowatt three-phase generator.

To the second class belongs also the Rateau turbine, which is an impulse or action turbine of a multicellular type having about nine pressure stages of the De Laval kind, instead of two or three as in the Curtis arrangement, which, however, differs further in having two or more velocity steps on each wheel as already described. When the initial steam pressure and the vacuum are moderate the number of wheels required is small, and they are now generally enclosed in one casing. An external view of a 60-b.h.p. Rateau single-casing turbine is illustrated in fig. 131, and a complete section of the machine, which is manufactured by Messrs. Fraser & Chalmers, is given in fig. 132. Each turbine element or stage, of which in this particular example there are nine, consists of a fixed distributing ring and a rotating wheel, to which live steam is admitted through the controlled valve C and the passages B. D and E are

the first sets of wheel and guide vanes respectively, and F is the exhaust. Thin sheet-steel discs, provided with peripheral nickel-steel vanes, are used for the moving wheels, and a number of these are shown assembled upon the shaft in fig. 133. Owing to

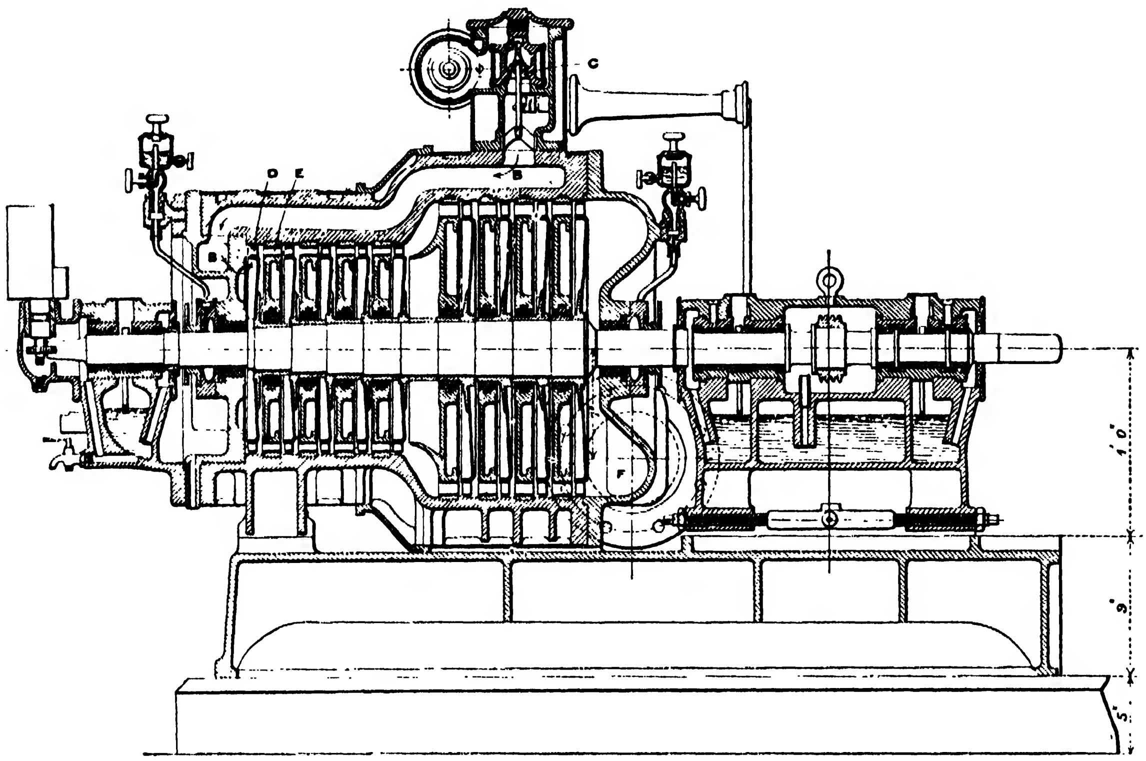

Fig. 132. Rateau Steam Turbine: Sectional Arrangement

the large percentage of nickel in the steel used for the vanes, rusting is largely prevented, and the life is increased even when using highly superheated steam. Around the vanes are fitted shrouding rings into which the tips are riveted, thus improving the rigidity and reducing the possibility of accidental stripping. Between the moving wheels are

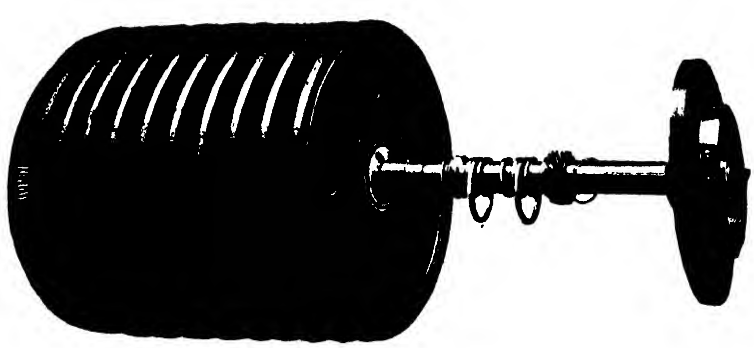
Fig. 133. Rotor Discs of Rateau Turbine

placed the fixed distributing diaphragms, several of which are shown in fig. 134. In the first diaphragm through which the high-pressure steam passes the distributing vanes are placed upon a portion only of the circumference, and as the volume of steam increases in the succeeding elements a correspondingly larger proportion of the circumference is

used. As the steam follows a spiral course in its passage through the turbine, the apertures of the succeeding discs are placed with a certain relative angular advance depending upon the speed of rotation, so that the steam discharged by one wheel may enter the nozzles of the next distributor without shock and consequently without loss of kinetic energy. Turbines of the Rateau type are also manufactured by the Oerlikon Maschinenfabrik, of Switzerland. An example of an Oerlikon 300-h.p. turbine contained in a single casing is illustrated in section in fig. 135, and fig. 136 represents a similar 1500-kilowatt turbo-generator set. Sufficient description has already been given of the action of the steam in the turbine, but the diagram fig. 137 will help to explain the changes undergone by the steam in its passage through the various expansion nozzles and wheel vanes. Each of the twelve stages indicated in the diagram by Roman numerals consists of three portions, corresponding to the guide wheel, moving wheel, and the intervening space. Following the curves from the entrance of the steam to the exhaust, it will be seen that in the first guide wheel there is a fall of the pressure curve I, with a corresponding increase of the velocity of the steam and therefore of the kinetic energy.

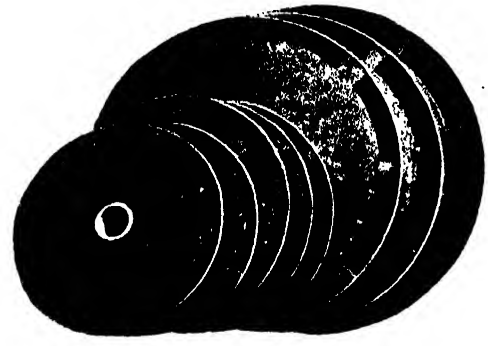

Fig. 134.—Fixed Guide Vanes of Rateau Turbine

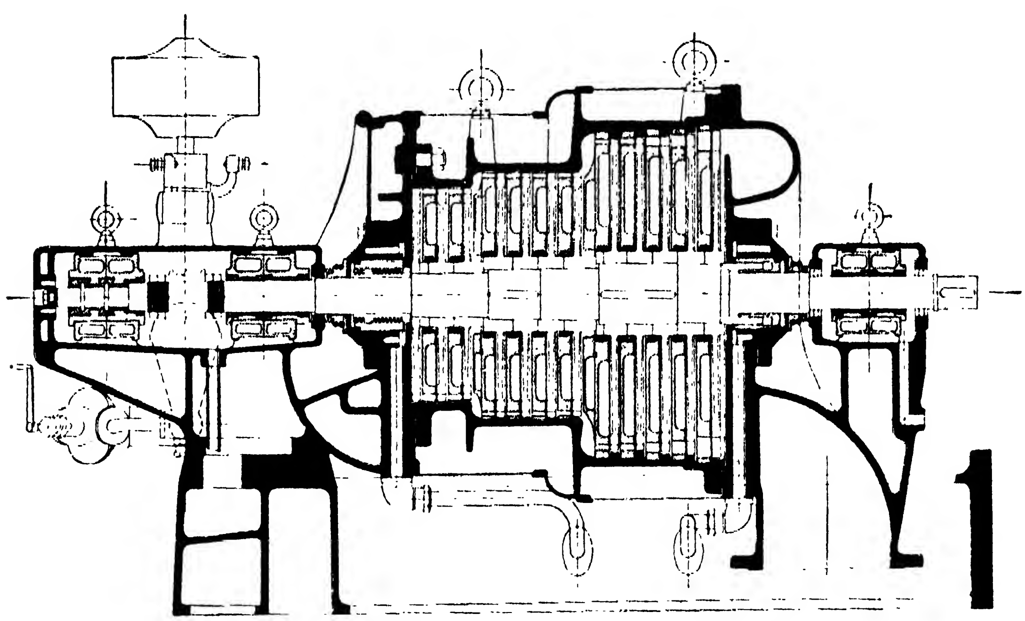

Fig. 135. Rateau Turbine by the Oerlikon Co. of Switzerland

This kinetic energy is absorbed in the moving wheel, where it is transformed into mechanical work, and, as indicated in the curve II, the velocity falls but the pressure is not altered, as no expansion takes place in the moving wheel vanes. Between the fixed and the moving portions there are provided clearance spaces, which are made as small as possible consistent with safety; and although the diagram shows

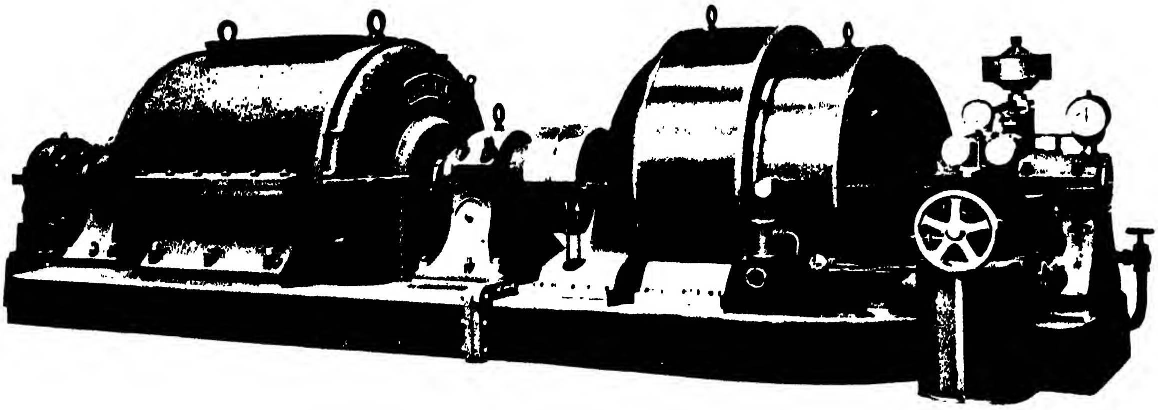

Fig. 136.—1500-Kilowatt Rateau Turbo-Generator

the pressure and velocity of the steam in the clearance spaces as not varying, there are in practice certain losses due to shock and the formation of eddies. In the second element of the turbine a further amount of the pressure energy is converted into velocity energy by the second set of fixed vanes, and this energy is in turn absorbed by the next moving wheel, until at the last element the steam is expanded down to the pressure of the condenser, by which time practically the whole energy has been transformed. Curve I of the diagram is approximately the familiar adiabatic expansion curve of the ordinary reciprocating steam engine, and if the stages had been more numerous the curve would have been still more continuous. Referring to the section fig. 135 it will be seen that the fixed guide discs are carried inwards to the shaft, so that the possible leakage space is greatly reduced. Owing to the differences of the pressures across the various elements there is a tendency for the steam to leak past the fixed guides, unless some precautions are taken to avoid it; but as the differences of pressures are small the leakage is not serious. In the De-Laval turbine there is no such tendency, as the pressure throughout the moving wheel chamber does not vary, and the clearance spaces may be made correspondingly

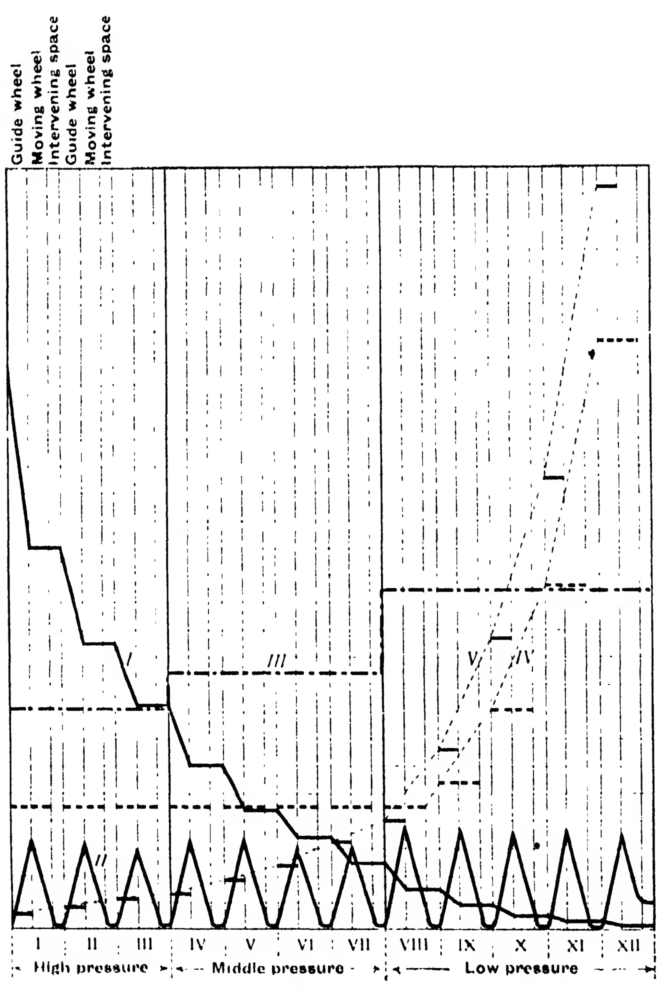

Fig. 137

greater. As the pressure of the steam falls its volume increases, necessitating a corresponding increase in the cross section of the steam passages, as shown in the section and indicated in the diagram. In the diaphragms of the first stage through which the steam passes the guide vanes are situated upon a portion only of the peripheries, and in the succeeding stages the proportion is increased, until at the final stage the apertures occupy the whole circumference.

One of the turbo-generators recently installed by the Oerlikon Company at the Woikowice Colliery in Russian Poland is illustrated in fig. 136. The effective output of the turbine is 2300 b.h.p., and it is arranged to run either with saturated steam or with steam superheated to 250° C. at a pressure of 10.5 atmospheres absolute. All three stages—high, middle, and low pressure—are contained in one casing, and this was the first example of a mono-cylindric turbine of this type for so large an output. Directly coupled to the turbine is a three-phase generator of 1500 kilowatts at 2000 volts and 50 cycles, the speed of rotation being 1500 per minute. Another interesting type is illustrated in fig. 138. As before, the generator is carried directly upon the turbine shaft, but the arrangement is vertical instead of horizontal, the weight being carried upon a suitable step bearing. This particular turbine has been installed to utilize the exhaust steam from an existing high-pressure steam plant, the steam being supplied to the turbine at a pressure of only 14.2 lb. per square inch, with a vacuum of 1.4 lb. per square inch induced by means of an ejector-condenser. The consumption is about 50 lb. per kilowatt hour. Reference will again be made in a later section to the utilization of exhaust steam in turbines.

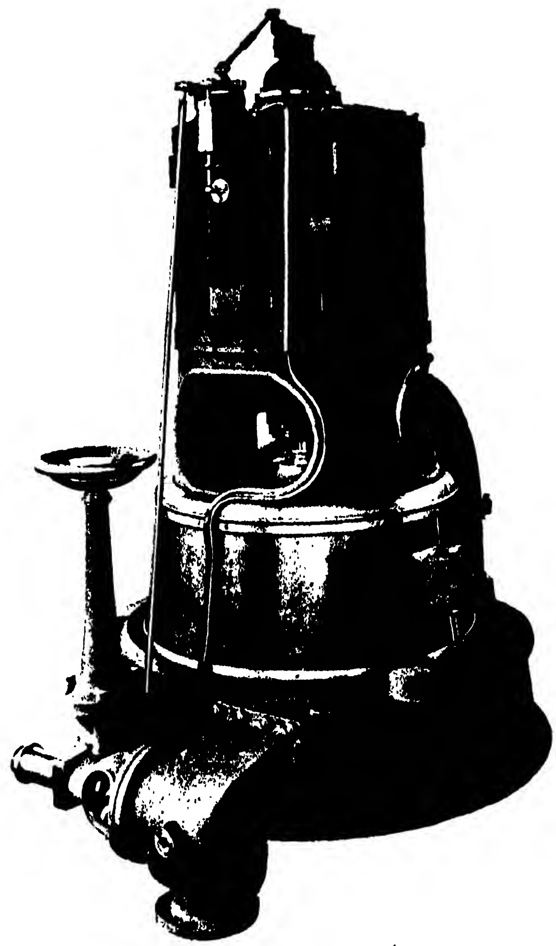

Fig. 138.—Vertical Turbo-Generator by the Oerlikon Co., Switzerland

There are several other types of multicellular impulse turbines that have made considerable progress within the last year or two, but, however interesting the details, the principal features differ so little from either the Curtis or the Rateau turbines that a detailed description cannot be given here. Of these turbines the most successful are the Zoelly—the details of which are fully illustrated by means of the cardboard model at the commencement of this chapter,—the Riedler-Stumpf, and the Escher-Wyss.

Velocities of a more moderate amount, suitable for the direct driving of ordinary electrical plant and for marine work, are obtained in the Parsons turbine by dividing

the whole expansion of the steam over a large number of successive stages, suitably proportioned to give a small fall of pressure in each stage. So far as the fixed guides are concerned, there is essentially little difference between the Parsons type and the impulse turbines already described, but, as illustrated in the diagrams figs. 120 and 121, the passages through the moving vanes of the impulse turbines have a uniform cross section when measured perpendicularly to the direction of the flow of the steam, while the section is not constant in the reaction wheel. Kinetic energy is thus generated in the compound turbine not only in the fixed blades, but also in the moving vanes, which convert the whole kinetic energy thus produced into work, and the overall

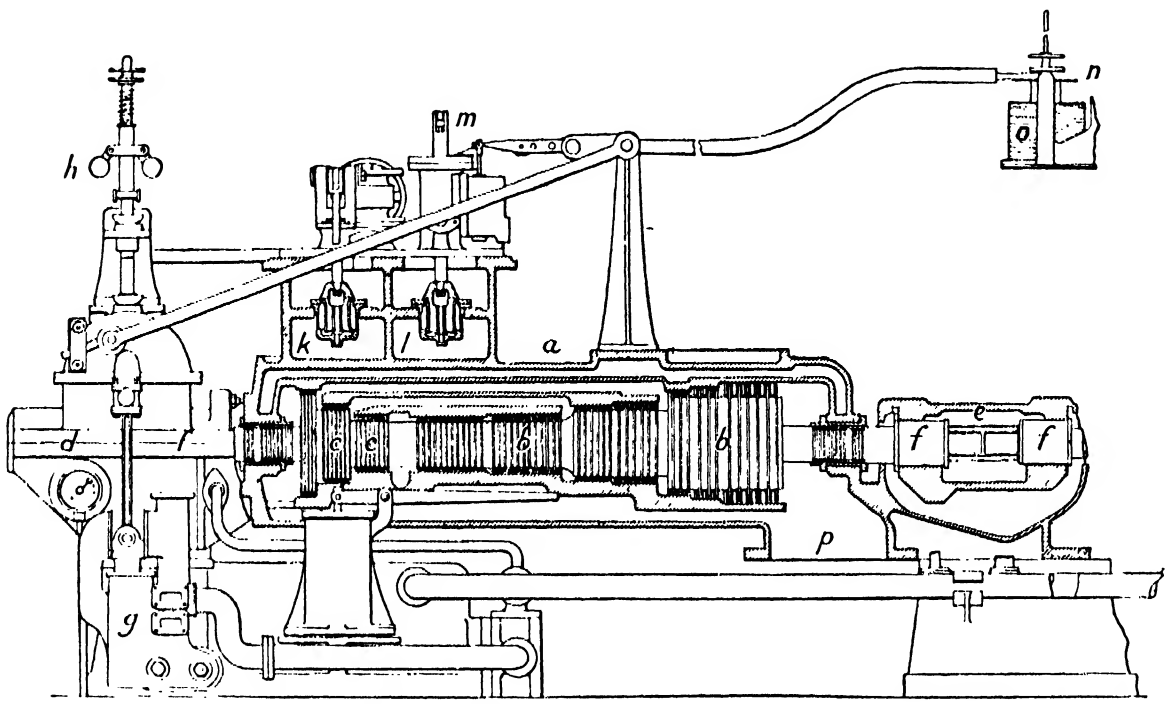

Fig. 139.—Parsons Steam Turbine for Direct Driving of Dynamos

length of the turbine is considerably reduced by making the moving wheel serve a double purpose.

For land service the Parsons turbine has proved itself to be admirably suited, and in many large electrical stations it is being adopted to the complete exclusion of the reciprocating engine. At sea, however, the progress has not been so rapid, as the speed at which the propellers can be efficiently run is as yet lower than the efficient speed of the turbine which can be conveniently installed. By sufficiently increasing the diameter of the rotor the speed of rotation could be reduced, while retaining the high peripheral velocity required for the efficient absorption of the kinetic energy, but the weight of the plant would exceed that of a reciprocating system, and at the present time the saving in weight in many actual marine turbine installations does not amount to more than 5 per cent.

A complete section of a Parsons compound turbine, designed for the direct driving of dynamos, is illustrated in fig. 139, from which it will be seen that the stages are divided into three sections, which may be called the high-pressure, intermediate, and low-pressure

turbines. This arrangement is adopted for manufacturing reasons, as the cost would be prohibitive if each stage were made larger than the preceding one. From the rotor project the rings of vanes, which rotate past the rings of guide blades attached to the casing *a*. Looking down upon the surface of the rotor in the direction of the length, the relative positions of the fixed and the moving vanes would be as shown in fig. 140, the sets of fixed guides shaded in the illustration being those which expand the steam and direct its flow upon the sets of moving blades. Live steam from the boiler is admitted through the governed valves *k* and *l*, fig. 139, to the chamber at the beginning of the high-pressure portion immediately behind the dummy piston marked *c*, and, after its energy is abstracted by the rotor *b*, the steam is exhausted through *p*. Admission thus takes place around the whole periphery, and in this respect it differs from the impulse types already described, in which full admission only takes place in the later stages. As the pressure of the steam falls, and as its energy is abstracted in its passage through the turbine, the volume increases, necessitating a corresponding increase of passage area through the vanes and guides; but in practice this condition is only partially satisfied by increasing the blade heights of succeeding sets of stages. Thus there are, in the example shown, two heights provided in each of the high-pressure and intermediate turbines, and three in the low.

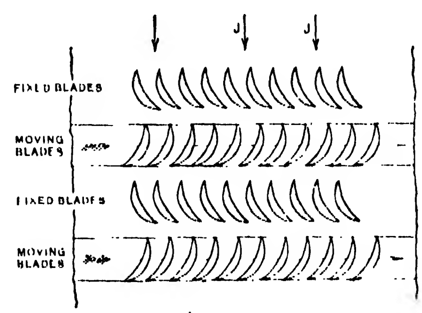

Fig. 140

Before proceeding with the actual manufacture of turbines, the Hon. Charles A. Parsons carried out a series of trials with shafts running at the high speeds which were required for the early small-diameter rotors. As a result of these experiments it was found that speeds of 40,000 revolutions per minute could be safely maintained without excessive vibration, by providing in the bearings a certain amount of freedom combined with transverse frictional resistance. In the first machines the bearings were provided with a series of discs fitted alternately to the shaft and the bush, the whole series being pressed together by a spiral spring. This arrangement proved quite satisfactory, and was fitted to a large number of turbines, but it was subsequently dispensed with in favour of a simpler arrangement, consisting of a number of loosely fitting concentric tubes separated from one another by films of oil, which effectually damped out the vibrations. In the illustration, fig. 139, *ff* are the bearings of the tubular type, and on the portion of the shaft which passes through the casing are shown the annular rings and shaft flanges, which are almost in contact, and which prevent the loss of steam by offering only a restricted and long passage, or, as it is called, labyrinth, for the steam to pass through.

One advantage of the impulse turbine over the reaction type is the absence of end thrust, owing to the equality of the pressure on both sides of each of the moving wheels. Any difference of pressure that may arise from pressure losses due to friction in the moving buckets of the impulse wheel may be compensated, so far as the end thrust is concerned, by altering the direction of the vanes at the exit. In the reaction turbine there is a considerable end thrust on the shaft, due to the fall of

pressure which takes place in the moving vanes, and arrangements must be provided for effectually neutralizing, or taking up, the thrust, as all possibility of fouling between the moving and the fixed rings must be avoided. By placing two equal turbines end to end, in one casing if desired, the thrusts could be made to balance one another, and this was the method adopted in the early land machines; but two small turbines form a less economical arrangement than one large one, owing to the higher speed of the two small ones, and to the larger ratio of the clearance spaces to the steam passage area. For this and other manufacturing reasons the double system was abandoned, one of the turbines being replaced by an equivalent series of balance, or "dummy" pistons, indicated in the illustration at *c*. There are three of these balance pistons, corresponding with the three low, intermediate, and high-pressure sections of the turbine, and each presents an area equivalent to the mean blade area of the section it is intended to balance. Thus the small piston under the pressure of the boiler steam balances the high-pressure section of the turbine, while the second and third pistons serve to balance the intermediate and low-pressure sections respectively. It will be seen that the face of the second piston is acted upon by steam at the intermediate pressure, led through a suitable passage formed in the casing, and that the third piston is in a similar way subjected to the low-pressure steam. For marine turbines smaller dummy rings are required, as the greater part of the turbine thrust is balanced by that of the propeller. Grooves and rings are formed on the dummy pistons to prevent leakage, as in the case of the shaft glands already described. Two governors are provided, one for controlling wide variations of the speed, and the other for small fluctuations or variations in voltage when the turbine is coupled to an electrical generator. If the speed rises unduly, the centrifugal governor *h* controls the balanced valve *k* by means of the lever shown in the illustration. A second and more sensitive governor controls the supplementary valve *l* through a relay valve *m*, which is operated by means of a long lever *m n*; but when it is desired to control the speed as the voltage of the dynamo varies, the solenoid arrangement marked *o* in the figure is adopted instead of the centrifugal governor. By connecting the coil *o* as a shunt across the dynamo terminals, the solenoid attached to the end of the lever at *n* is moved up or down as the voltage varies, and thus the valve *l* is operated. Oil is forced in a continuous stream through the bearings by means of the pump *g*, driven from the worm wheel of the governor *h*. At sea the conditions, so far as steam turbines are concerned, are very different from those on land, and the application of the turbine to the propulsion of vessels has not been so rapid. The chief limiting factor at present is the low efficiency of the propellers at the high speeds best suited to the turbine, and for a combined efficiency equal to that of a reciprocating plant the turbine efficiency must be considerably superior to that of the reciprocating engine. At the present time the most suitable form of propeller for a particular turbine vessel cannot with any certainty be predicted, and, until the conditions are better understood, the choice of a propeller will be more a matter of expensive experimenting than of design.

In January, 1894, a syndicate was formed at Newcastle-upon-Tyne, by Mr. Parsons, for the purpose of carrying out the costly preliminary experiments that were seen to be necessary before the turbine could be applied successfully to ships, and an experimental

vessel, the *Turbinia*, was constructed, the length being 100 ft., the beam 9 ft., and the displacement 44 tons.

By increasing the number of expansion stages the speed of rotation may be correspondingly reduced, as already explained, but there are objections to unduly increasing the overall length of the turbine, and in the *Turbinia* the complete expansion of the steam was, in the final arrangement, divided over three separate turbines arranged as a high-pressure, intermediate, and low-pressure series. There were thus three shafts, each of which was fitted with three propellers. Owing to the non-reversible nature of the turbine, a separate reversing turbine was coupled to the centre shaft, which, under normal conditions, was driven by the low-pressure turbine.

Very remarkable results were obtained at the trials of the vessel, the maximum speed of $34\frac{1}{2}$ knots being attained with an i.h.p. of 2300. At 31 knots the total steam consumption for all purposes was ascertained to be $14\frac{1}{2}$ lb. per indicated-horse-power hour.

Further trials were made in 1898-1900 by the Admiralty, with the torpedo-boat destroyer *Viper*, and, later, with a second destroyer, the *Cobra*. Both vessels were, unfortunately, lost at sea, but very valuable experience was obtained from them.

Since the building of the *King Edward*, in 1901, by Messrs. William Denny & Bros., of Dumbarton, the turbine has been applied with great success to a large number of express passenger steamers of the cross-channel type, and to large yachts, in which smoothness of running is almost of as much importance as economy. Experience gained with these vessels seems to indicate in many cases that the speed is maintained in all weathers, which probably is due to the deeper immersion of the propeller blades resulting from the smaller diameter, and that the propellers do not race in a heavy sea-way. Turbine vessels, when starting, gather way very quickly, as the starting torque is about 50 per cent greater than the normal running torque. As the steam enters the turbine it acts upon the stationary blades, and exerts a force much greater than when the blades rotate with the steam, because the velocity of the steam relatively to the blades is then much less.

Almost without exception all the recent battleship and cruiser additions to the British fleet have been provided with turbine machinery, as the system offers certain strategic advantages apart from any actual saving in working costs.

For large Atlantic liners, the Allan Line Company was the first to adopt the turbine, which was installed in two of their new vessels, the *Victorian* and the *Virginian*, each having machinery of 12,000 i.h.p., estimated to give a sea speed of 17 knots. These boats failed to completely realize all expectations, but the results have recently been considerably improved.

Preparatory to the construction of the two great turbine ships, the *Lusitania* and the *Mauretania*, the Cunard Company added to their fleet the *Caronia* and the *Carmania*, sister ships of 30,000 tons displacement and 21,000 i.h.p., and from these ships much valuable experience has been gathered. Both the *Lusitania* and the *Mauretania* have been fitted with turbines of 70,000 i.h.p., calculated to give a speed of $24\frac{1}{2}$ knots. With turbines of this large size it is hoped that the consumption will be phenomenally low, and that the cost of maintenance and supervision will also be small.

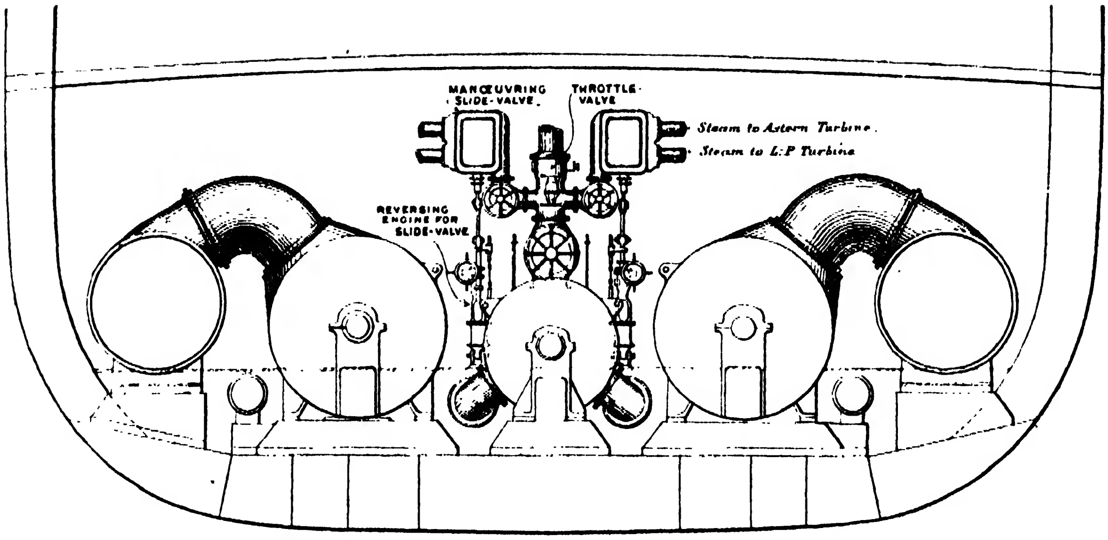

Fig. 141.—Arrangement of Parsons Marine Turbines: End View

A cross-sectional elevation and a plan of the engine room, showing an arrangement of turbines as installed upon an Atlantic liner, are given in figs. 141 and 142, taken from a paper read by Messrs. Parsons & Stoney before the Institution of Civil Engineers. Steam is admitted to the high-pressure turbine on the centre shaft, and then passes to

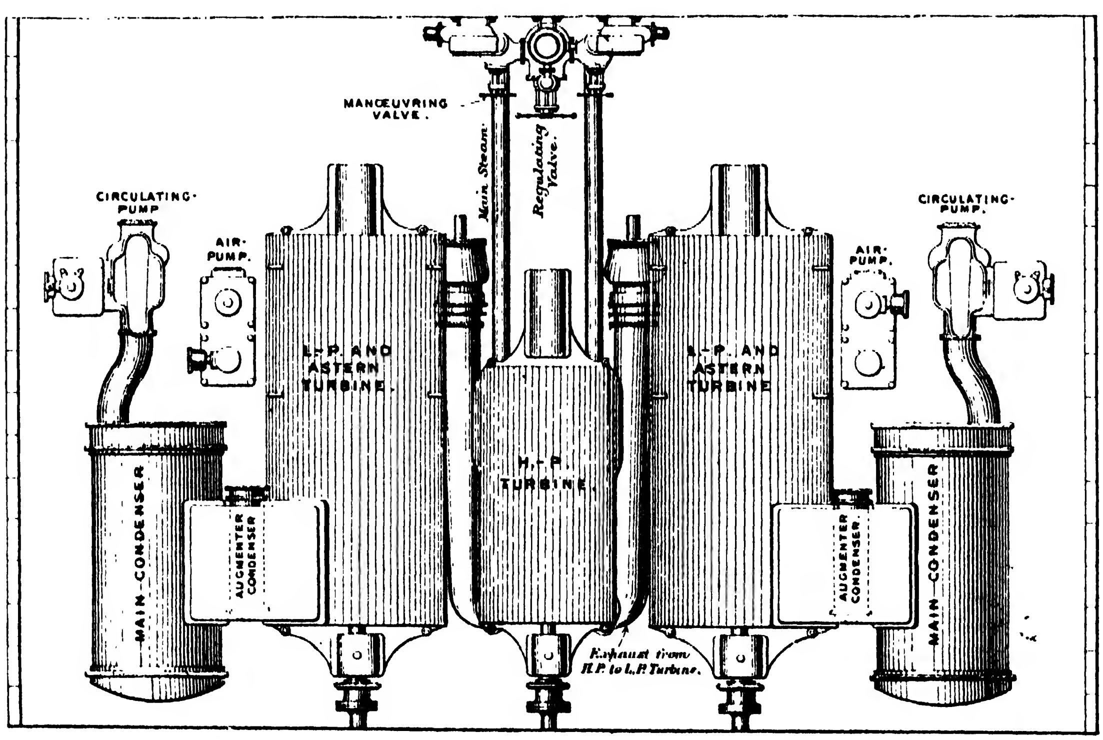

Fig. 142.—Arrangement of Parsons Marine Turbines: Plan

the two low-pressure turbines on the wing shafts, from which it is exhausted to the condensers shown at each side. On each side shaft is fitted an astern turbine, contained in the low-pressure casing. During the forward running the astern turbines rotate idly, and with very slight loss, in the vacuum of the condenser.

Certain improvements have been effected in the details of the Parsons turbine by licensees of the Parsons Company. Messrs. Willans & Robinson, of Rugby, have

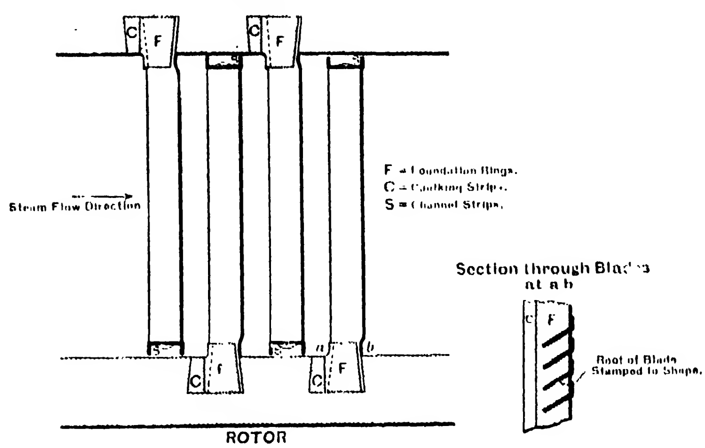

Fig. 143

introduced an improved system of binding together the tips of the blades and of attaching them to the rotor body. The blades for both the casing and the rotor are assembled in half rings upon correspondingly halved foundation rings F, fig. 143,

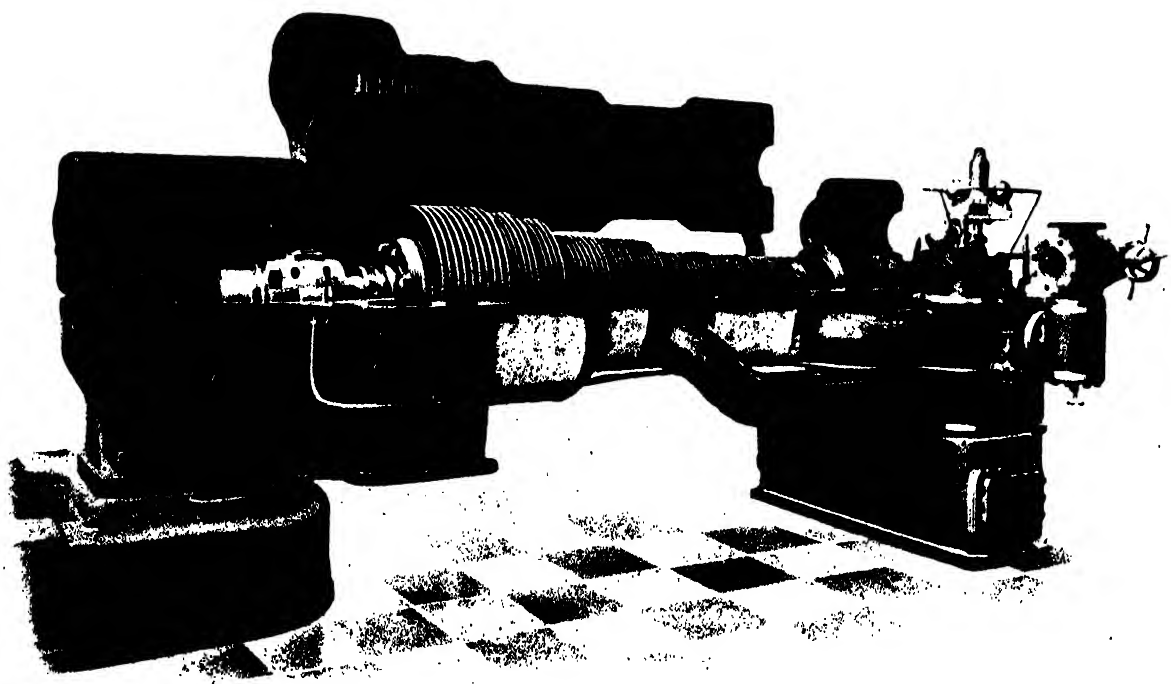

Fig. 144. 1000-Kilowatt Willans-Parsons Turbine opened up for Examination

which are fitted into dovetailed grooves on the rotor or casing, and secured by caulking strips C. Into the shrouding rings S are riveted the tips of the blades, which are provided with suitable projections for riveting over. When the tips of the blades

are bound together by shrouding rings instead of only by wire at the sides, as in the Parsons design, the clearance-spaces, and therefore the leakage losses, may be considerably reduced, and, further, there is less danger of the vanes being stripped off in

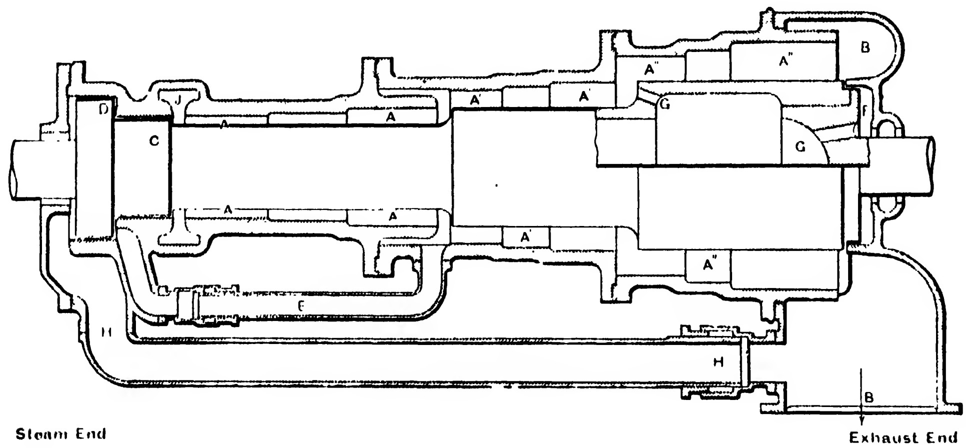

Fig. 145. Willans-Parsons Turbine Balance Pistons

the event of the protecting shrouding ring coming into contact with the opposite face, through wearing of the bearings or other accidents. The Willans-Parsons 1000-kilowatt turbine, illustrated in fig. 144, shows clearly the arrangement of the

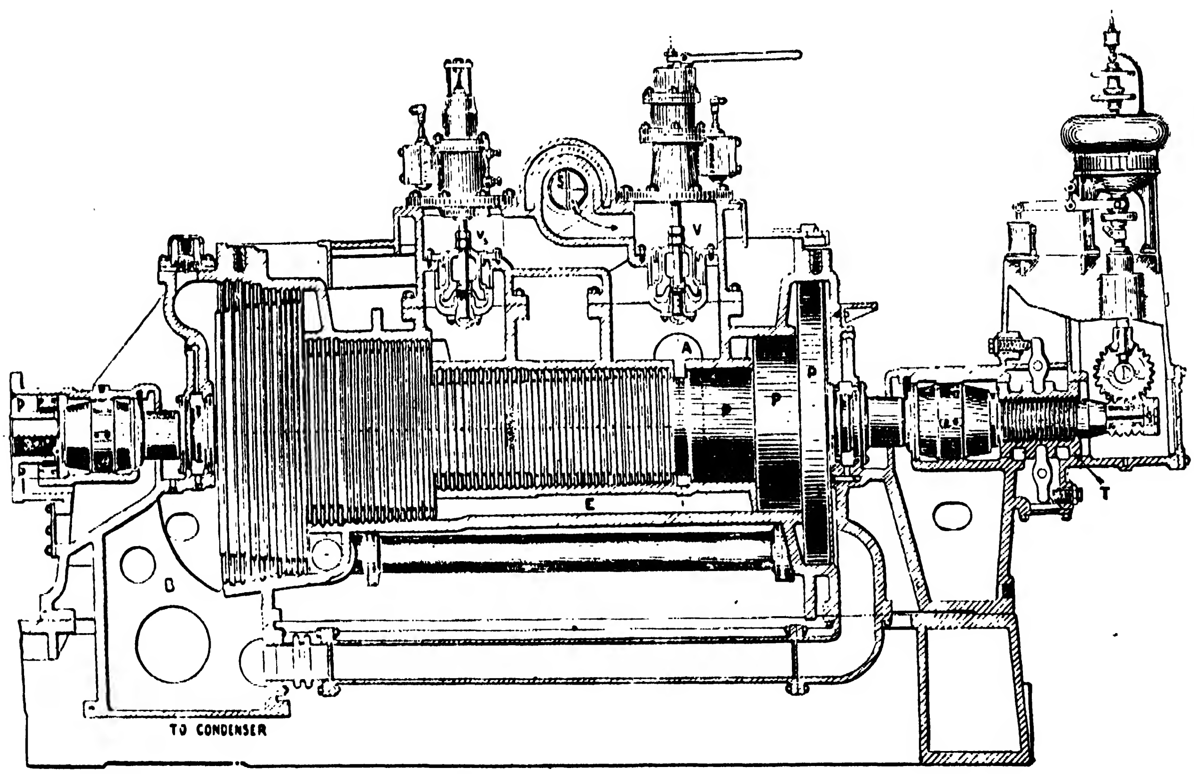

Fig. 146.—Section of Westinghouse-Parsons Turbine

rotor, and the method of hinging the upper half of the casing so that it may be opened up for inspection or repair without fear of damaging the blades. One other important modification is that adopted for balancing the thrust of the low-pressure

blades, by admitting steam to the face of the low-pressure end of the rotor, as shown in fig. 145. As in the Parsons design, two dummy pistons, C and D, are used to balance the thrusts on the high and the intermediate blades respectively, but the third large-diameter piston may be dispensed with, and thus the weights of the rotor and the casing at the high-pressure end are considerably reduced and the length diminished. Low-pressure steam is admitted through the passages G G to the end face F, the area of which is made equal to the mean area of the low-pressure blades. It will be seen from the illustration that the steam connections are all provided with telescopic portions

Fig. 147.—600-h.p. Westinghouse-Parsons Steam Turbine, opened for Inspection

to permit of expansion when first the steam is admitted to the casing. Great care must be exercised in uniformly heating up a steam turbine before starting, as otherwise unequal expansion may cause the rotor and the stationary blades to foul each other, and the casing also may be damaged. Once the casing has safely reached the working temperature there is less danger, although, under normal conditions, the one end is at the temperature of the high-pressure steam and the other at that of the condenser.

A sectional view of a Westinghouse-Parsons turbine is given in fig. 146, and as the drawing is sufficiently clear and self-explanatory the details need not be further described. Fig. 147 shows a 600-h.p. turbine with the upper casing opened up for inspection, and fig. 148 is an interesting comparison of the spaces occupied by a 5000-kilowatt turbo-generator of the Westinghouse Parsons type and by an equivalent

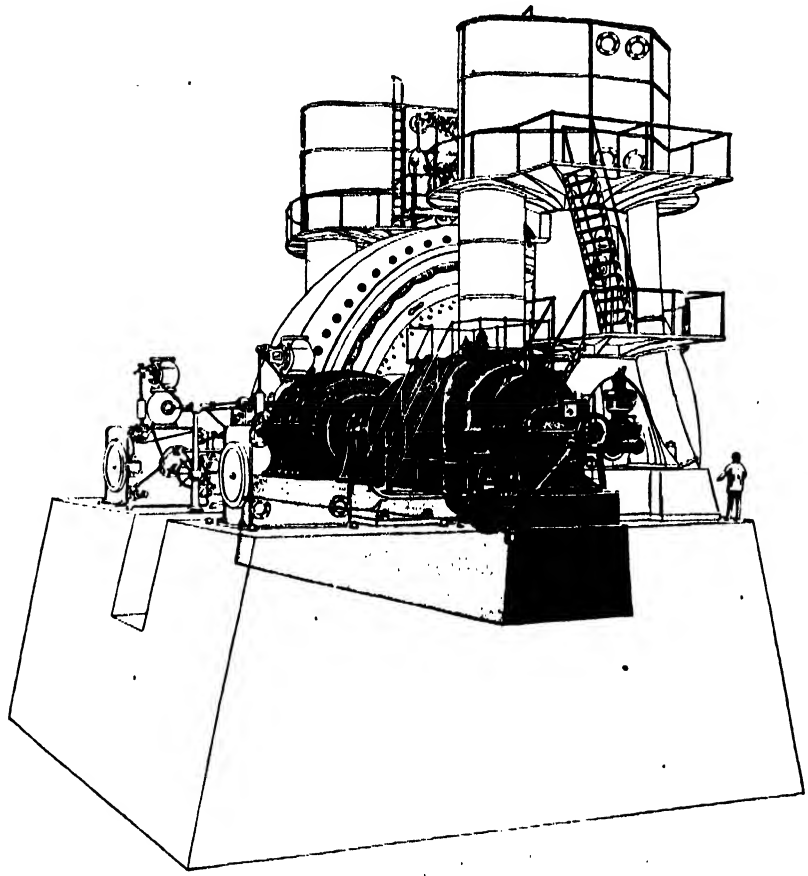

Fig. 148.—Comparative Sizes of a Turbine and a Reciprocating Engine Plant of Equal Powers

reciprocating engine and generator. Not only is there a great saving in floor space and in height, but the foundation required for the quick-running turbine is inconsiderable

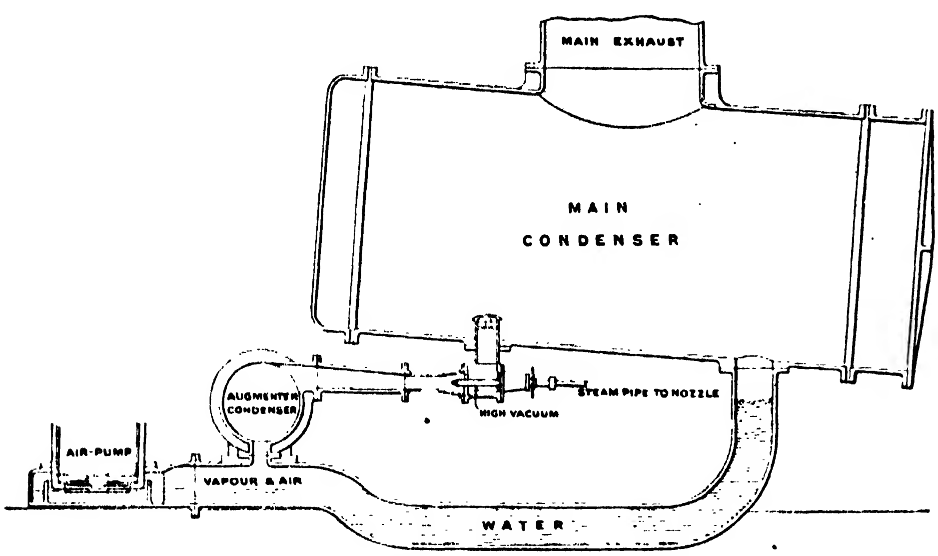

Fig. 149.—Turbine Condenser with Parsons Vacuum Augmenter

compared with that required for the reciprocating set, and the cost of the turbine power house is correspondingly small.

Good condensing arrangements are an essential part of the steam-turbine plant,

as the turbine is admirably suited to the full utilization of a high vacuum. In ordinary practice, with well-designed air and circulating pumps, and an allowance of 1 sq. ft. of condenser surface per indicated horse power, a vacuum of 26 to 27 in. may be maintained. This may be raised to $27\frac{1}{2}$ or 28 in. when required for the turbine, by increasing the surface per indicated horse power to $1\frac{1}{2}$ sq. ft., and by increasing the supply of cooling water. Mr. Parsons has further improved the performance of the condenser by adding a vacuum augmenter, which consists of a steam aspirator placed between the main condenser and the air pump, as shown in fig. 149. The jet of steam passing through the restricted nozzle extracts a large proportion of the air and vapour from the main condenser and forces it into the augmenter condenser, from which it is drawn away by the main air pump. Recently the consumption of steam in the jet has been reduced to from 1 to $1\frac{1}{2}$ per cent of that being dealt with at normal load in the main condenser, and with this expenditure the reduction of the steam consumption in the turbine is about 8 per cent.

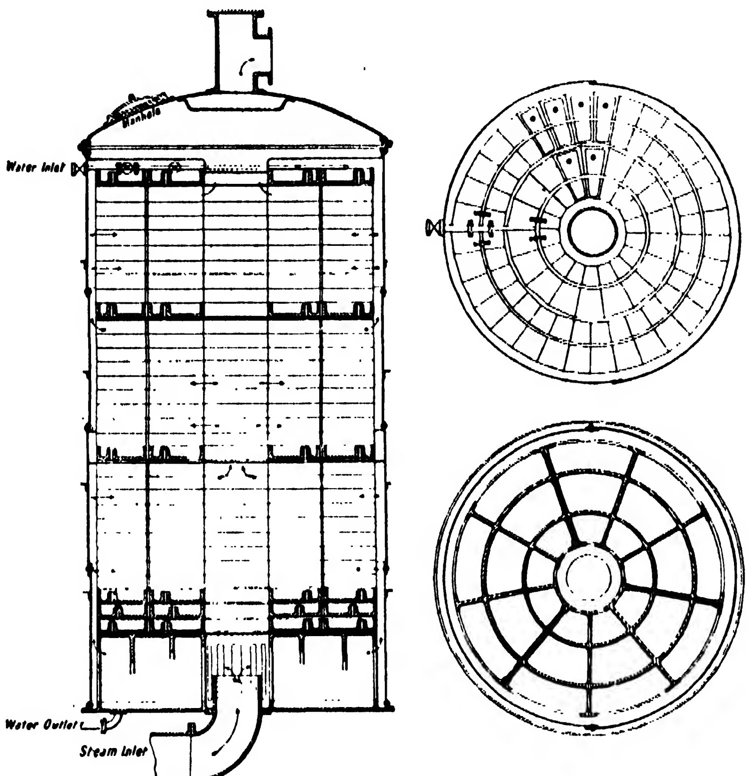

Fig. 150. Rateau's Accumulator with Cast-iron Trays

Exhaust steam turbines are only now being generally installed, although the combination of the high-pressure reciprocating engine with a low-pressure or exhaust turbine was patented by Mr. Parsons several years ago. It is not possible in the ordinary reciprocating engine to carry the expansion as far as in the turbine, owing to the large capacity that would be required in the low-pressure cylinder, and to the condensation losses that would result from the large and intermittent changes of temperature. Many large reciprocating engines installed throughout the country do not work condensing, and this is particularly the case in rolling mills and collieries, where the working is so irregular as to interfere with the efficient action of a condenser. By installing suitable condensing plant and receivers and an exhaust steam turbine, the energy of the exhaust steam may be utilized instead of being rejected, and, without adding to the boiler capacity, a large increase of power, amounting in certain cases to as much as 70 per cent, may be obtained. Owing to the intermittent nature of the exhaust from reciprocating engines it is generally necessary to install receiving chambers for the purpose of steadying the steam supply to the turbine, and when the exhaust is very irregular, as in the case of rolling engines, a regenerator system equi-

valent to a heat flywheel is required. Professor Rateau has successfully applied the system of thermal storage to the Parsons exhaust-steam turbine, and arrangements have been made by the respective patentees for working the patents in conjunction. In the first type of steam accumulator, fig. 150, devised by Professor Rateau, the exhaust steam is led into a vertical chamber filled with shallow cast-iron trays, in which the condensed water accumulates. As the steam passes backwards and forwards over the large surface exposed, a rapid interchange of heat takes place, heat being absorbed when the steam supply is great and given out again when the flow is reduced. A more intimate mixture of the steam and the water is obtained in the second type, illustrated in fig. 151, which depends for the storage of the heat on the absorbing power of water only. It consists of one or more horizontal cylindrical chambers containing

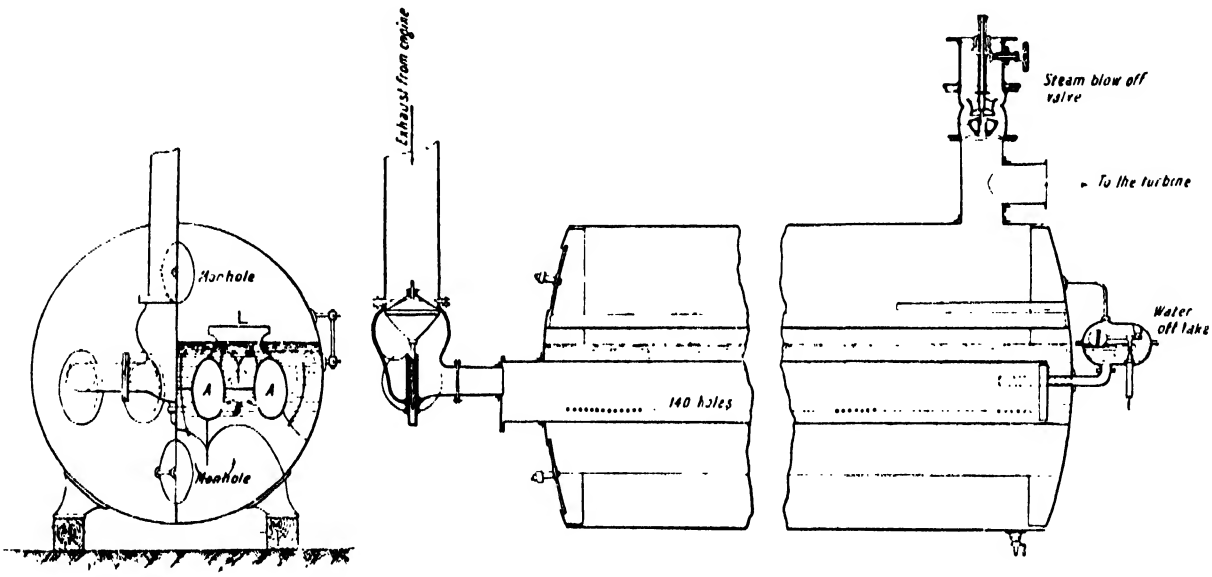

Fig. 151. Details of Rateau's Water-Accumulator Regenerator

a number of longitudinal elliptical steam tubes A, pierced with rows of small holes and submerged in the water spaces B. Steam enters the elliptical tubes through a non-return valve at the left end, and escapes into the water spaces B through the tube perforations. When the steam supply from the main engines is reduced, the water liberates the latent heat it has absorbed, and an even flow of low-pressure steam is given off. At the same time the steady demand of the low-pressure turbine, which utilizes the steam, reduces the pressure in the accumulator, and the steam still retained in the inner tubes then forces its way through the perforations and helps to maintain the circulation of the water and the liberation of steam. Other systems have been proposed, in which the heat is absorbed by scrap iron instead of only water, but it is not necessary to describe them here. When it is required to run the turbine even although the main engines are stopped, the turbine must be supplied with live steam, and in these cases special reducing valves are fitted on the boiler connection to reduce the steam to the working pressure of the turbine.

RIEDLER-CURTIS STEAM TURBINE

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1. Brick-work Foundation.
2. Bedplate of Machine.
3. Foundation Bolts.
4. Sheet-metal Cover.
5. Oil-feed Pipes to the Bearings.
6. Oil-return Pipes from the Bearings to the Pump.
7. Oil Pump.
8. Lower Half Turbine Casing.
9. Casing Flange.
10. Casing holding down Bolts.
11. Upper Removable Half of Casing.
12. Lifting Eye Bolts.
13. Gland Casing.
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16. Bearing Bushes.
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27. High-pressure Rotor Disc.
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30. Low-pressure Stator Guide-blade discs.
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32. Main Shaft.
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Section III

THE STEAM LOCOMOTIVE

THE STEAM LOCOMOTIVE

When the first great development of railways took place, half a century ago, lines were constructed, and tunnels cut through the hills, with but little idea of providing for future demands, the magnitude of which was probably unthought of.

Over these early routes locomotives of ten times the power now require to run, and this has involved the concentration of the large boiler power required into a space limited both in height and in breadth, the latter restriction being due to the narrow gauge or separation of the rails adopted. Designers of locomotive engines have thus to face restrictions that are met with in no other branch of steam engineering.

As in the case of many other great inventions of universal application no one country or man can lay claim to the highly perfect locomotive of the present day. British, American, and Continental engineers have all contributed, although the different conditions met with in these countries have led to the adoption of types best suited to their particular requirements.

The stages in the development of the locomotive are as follows:—

From 1680 to 1784 repeated attempts were made to produce self-propelled vehicles for use on the common highways.

In 1769 the first steam carriage was practically tried with some success..

In 1804 a trial was made with the first locomotive running on rails.

1814 to 1830 was a period of much experimental working, and thereafter from 1830 may be dated the practical development of the steam locomotive.

The first proposal to substitute self-propelled vehicles for horse-drawn carriages on the public highways was contemporaneous with the invention of the steam engine itself. In 1680 Sir Isaac Newton suggested the reaction of a jet of steam escaping from a boiler as a suitable way of driving a road carriage; but, as may be readily understood, the idea was never practically realized.

James Watt, in 1784, filed the first patent for such a vehicle, and later constructed a model locomotive which developed a speed of about 8 miles an hour. The idea was not carried further than the model, which is now preserved in South Kensington Museum, London, until in 1790 it was revived by Nathan Road.

To a Frenchman, Nicholas Joseph Cugnot, belongs the credit, in 1769, of not only devising but also realizing the first steam carriage of any practical value. The trials showed that with certain modifications the carriage might have been run in actual service with some success. Its further development ceased on the death of the inventor. Cugnot's steam carriage is now in the collection of the Conservatoire of Arts and Science in Paris.

In 1756 Olivier Evans, the constructor of the first steam engine in America, suggested its use without a condenser for locomotives. That he realized the practical value of the idea is evident from some of his writings. He had no doubt that his machine would be able to steam against the current of the Mississippi, and to earn large profits running on the public highways. The time would come, he prophesied, when passengers would be carried in steam carriages as fast as the birds could fly, that is from 15 to 20 miles an hour. A traveller leaving Washington in the morning would take breakfast in Baltimore, dine in Philadelphia, and have supper in the evening at New York. Several machines were built by him, but owing to his death in 1819 they were not put into actual service.

Considerable progress was made by several British engineers, as, for example, Trevithick in 1802, Griffith in 1821, Gurney in 1827, and Hancock in 1836. The steam carriages of the latter ran at a speed of 10 miles an hour, from Paddington, for 5½ hours per day. One of the carriages attained a regular speed of nearly 20 miles, but owing to the unsuitability of the roads, and to the strong opposition of the stage-coach proprietors, the carriages were forced to withdraw, and progress accordingly was arrested.

In 1804 Trevithick, a pupil of Murdoch, built a locomotive to run upon rails. The engine worked for several weeks on the Merthyr-Tydvil Railway in South Wales, but the speed attained was very low, and an accident soon stopped further trials. Many of the essential features of this engine are to be found in the locomotives of the present day: the fire grate was placed for the first time inside the boiler, a condenser was dispensed with, and the draught was forced by means of the exhaust steam. The cylinders were placed side by side with the pistons, driving cranks set at right angles to one another. Insufficient resources compelled the inventor to abandon further attempts to improve what appears to have been a very promising engine.

About this time the opinion seems to have been formed that a locomotive had not sufficient adhesion upon the rails to draw even very light loads up a small incline. To overcome this supposed difficulty, Blenkinsop in 1811 adopted a rack rail with which the toothed driving wheel of the engine geared; but the wear and tear were found in practice to be excessive. Chapman, in 1812, made use of a long chain lying between the rails, with one turn coiled round a winding drum on the engine. The engine in this way pulled itself along, towing its load after it. A third idea, more ingenious but less practical, was experimentally tried by Brunton in 1813. The engine in this case pushed itself along by means of two jointed propelling levers, which were alternately raised and thrust out backwards, imitating to some extent the action of the hind legs of a horse. A serious accident brought the trials to a sudden close.

In 1813 Hedley revived Trevithick's arrangement, and proved that very practical

results could be obtained from locomotives built upon its principles. Hedley's first locomotive was built for the Wylam Colliery on the Tyne, where it ran for some time. It was a very small engine running upon four wheels, and working with steam at 4 atmospheres pressure. At a later date eight wheels were fitted in place of the original four. One of these locomotives, which worked until 1862, is now preserved in South Kensington Museum.

So far as mechanical details are concerned the locomotive had reached a state of considerable practical value, but the power obtainable was very low owing to the inefficient nature of the boiler. A French engineer, Marc Séguin, patented in 1827 a tubular boiler, and applied the idea in 1831 to a locomotive which ran upon a railway between Gisors and Rives-de-Giers.

Particulars of this locomotive are given below:—

Number of wheels—4	diameter, 4 ft. 3 in.
Tubular type boiler	working pressure 3 atmospheres.
Length of tubes	7 ft. 3 in.
Number of tubes	43.
Heating surface	250 sq. ft.
Diameter of cylinders	9.4 in.
Piston stroke	2 ft.
Total weight	6 tons.

George Stephenson, who was simply a working mechanic in the employment of Lord Ravensworth, designed and built a locomotive called the Blücher, which was placed on the Killingworth Colliery Railway in July 1814. It was succeeded by a second engine embodying several important improvements. Two cylinders were used, with their pistons driving separate cranks one upon each axle, the two axles being coupled together by means of a chain and sprocket wheels. Instead of using cast iron for the locomotive wheels, as had until then been the universal practice, Stephenson built them of wrought iron for the first time. He also invented a dynamometer, by means of which he was able to determine the pull exerted by his engines under various working conditions. In this way he demonstrated conclusively the great advantage of providing rails for the engine to run upon. From his measurements he showed that a locomotive running upon rails could pull a load ten times as great as could be drawn on the highway and at four times the speed. When Stephenson was appointed engineer of the Stockton and Darlington Railway he had more opportunity of developing his ideas. Until then locomotives had been used solely for mineral and general goods traffic, passenger trains being drawn by horses at a speed which was generally being recognized as too slow for the requirements of the times. Stephenson soon realized this, and applied one of his goods engines to the passenger service. This engine drew long trains of carriages at a speed of over 12 miles an hour, and helped greatly to develop the public taste for still more rapid means of locomotion. Although the Merthyr-Tydvil Railway was established as a railway company by Act of Parliament in 1803,

the Stockton and Darlington Railway, opened in 1825, was the first railway in actual public service. In 1828 the Liverpool and Manchester Railway Company, which had completed what was at that date the most substantial and best levelled railway in the country, offered a prize of £500 for the locomotive which would best fulfil the following requirements. The engine was required—

1. To burn its own smoke.
2. To weigh 6 tons and to draw a load of 20 tons at a speed of 10 miles per hour, and with a boiler pressure of 60 lb. per square inch.
3. The boiler to have two separate safety valves.
4. The engine to have 6 wheels and to be carried upon springs. The over-all height also not to exceed 15 ft.
5. The boiler to be capable of withstanding a pressure of 240 lb. per square inch.
6. The boiler to be provided with a mercury gauge indicating pressures above 45 lb. per square inch.
7. The engine to be ready for trial by the 1st October, 1829.
8. The price not to exceed £550.

Five locomotives were entered for trial:

1. The Cyclopede by Brandrith, Liverpool.
2. The Perseverance by Burstall, Edinburgh.
3. The Sanspareil by Hackworth, Darlington.
4. The Novelty by Braithwaite & Erksson, London.
5. The Rocket by Stephenson, Newcastle.

Of these five engines the first two were disqualified, and of the others the Rocket alone fulfilled the conditions of the trial.

The boiler of the Rocket was of the tubular type first introduced by Séguin, having a large number of smoke tubes running horizontally between the fire box and the chimney and traversing the water space. By the use of these tubes a greatly increased surface was presented to the action of the hot furnace gases, and the production of steam correspondingly increased. Twenty-five tubes were provided, each of 3 in. diameter. The boiler proper consisted of a built-up iron cylinder 40 in. in diameter and 6 ft. long, with a total heating surface of 110 sq. ft. At the one end of the boiler was placed the smoke funnel, and at the other end a rectangular chamber provided with grate bars at the bottom for the fire. In locomotives of the present day this arrangement of fire box is still adhered to, so far, that is to say, as the general idea is concerned. Around the fire box a water space was formed communicating with the boiler by means of two external tubes filled with water. No water space was provided over the top of the fire box; but considering the low working pressure of 50 lb. and the small temperature of the fire this was not essential. To preserve the inner surface of the fire-box plates a fire-brick lining was employed covering the front and sides for some distance above the fire grate. The cylinders were placed one on each side of the boiler and

inclined downwards, with the piston crossheads guided by slides and the connecting rods coupled to crank pins on the driving wheels themselves. Steam was distributed to the cylinders by separate eccentrics, one for each cylinder. The eccentric rods were made to engage pins on the slide-valve rod, so that the engine driver by disengaging the eccentric and placing it again in gear at the proper moment could reverse the motion of the engine. This primitive gab arrangement was replaced in later engines by Stephenson's fork gear, and still later by the Howe, or as it is called Stephenson link motion. All four wheels were of wood strapped with iron and provided with iron tyres. The main driving wheels were 4 ft. 8½ in. in diameter, and the two carrying wheels each 3 ft. 4 in. Engine and tender together weighed 7¾ tons, the engine being 4½ tons and the tender 3¼ tons. With coke as the fuel 0.17 lb. of the combustible were required to evaporate 1 lb. of water, and with this consumption a speed of 25 to 30 miles per hour was attained when drawing a train of coaches and 30 passengers. When drawing 13 tons of merchandise a speed of 28 miles an hour was attained. This competition and the remarkable success of the Rocket settled all doubts as to the great advantages obtainable from the use of rails, and also settled the general lines upon which the locomotive would require to be developed if the rapidly growing demands were to be met successfully. None of the other competing engines was able to fulfil in all respects the requirements. One developed a serious boiler defect and was compelled to withdraw from the contest. Another succeeded in attaining a speed of 15 miles an hour, but failed to cover the specified distance. The Rocket alone satisfied all the tests and was accordingly awarded the prize. The maximum speed was 29 miles an hour, a speed greatly in excess of what was demanded by the railway engineers. On the 15th September, 1830, the Manchester and Liverpool Railway was officially opened with a train of twenty-eight carriages and six hundred passengers, drawn by eight locomotives; and shortly afterwards six trains were running daily at a speed sometimes of 31 miles an hour. Stephenson's Rocket, which ran regularly on the route for several years, is now in the historical collection at South Kensington Museum. Great improvements were effected by Stephenson, particularly in the application of the Howe link gear for controlling the distribution of the steam to the cylinders. By 1842 he had increased the size of the locomotive boilers very considerably, and also the weight of the engine in order to get greater adhesion upon the rails. Three axles were adopted, instead of two as in the Rocket, and the driving-wheel diameter was also made greater. With the increase in the weight of the engines and trains it was found necessary to increase to a corresponding extent the strength of the rails used. The first rails weighed about 23 lb. per linear yard. This was soon increased to 50 lb. and upwards. At the present day, to meet the requirements of high speeds and heavy trains, rails weighing upwards of 100 lb. are commonly employed. Another stage in the development of the locomotive is marked by Crampton's locomotive, named after its designer. It was put into actual service in 1847, and at once surpassed all previous speed records. As may be seen from the illustration of the engine, in fig. 152, the driving wheels were of the unusual size of 5 ft. diameter, and were placed at the extreme end of the engine in order to clear the fire box, and to bring the centre of gravity of the engine as low as possible. If the axle of

the driving wheels had been placed farther forward instead of beyond the fire box, the boiler would have required to be placed at a considerable height in order to clear the axle and the gear. Crampton's engine, though capable of running at a high speed with light trains, was much too light for the heavier requirements of the goods traffic. It was found necessary to increase the tractive power by increasing the weight of the engine, and to couple together two or three sets of wheels by means of connecting rods coupled to crank pins on the wheels in order to obtain the necessary adhesion on the rails. Great improvements were made in the manufacture of the wheels, not only in their design but also in the greater mechanical accuracy of construction. Every improvement in these early days of engineering progress involved the devising of new methods of construction and suitable machinery, for the skill of the engineer was not sufficiently developed to undertake all that was required of it.

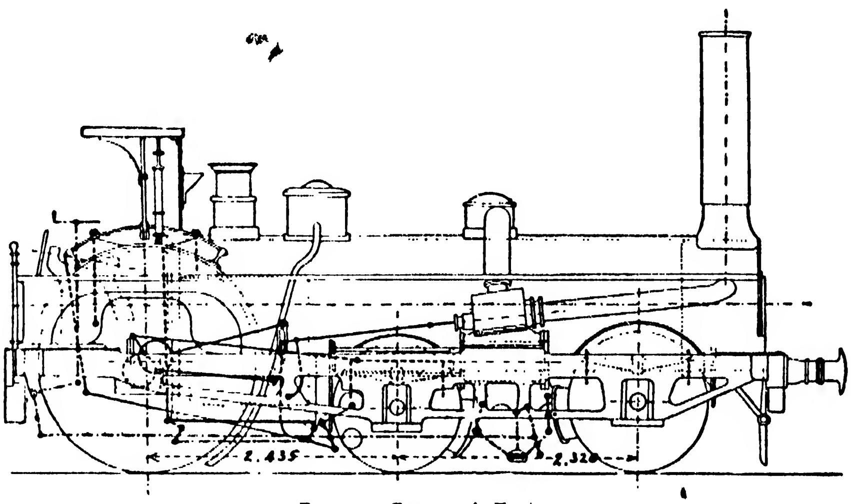


Fig. 152.—Crampton's Engine

In 1851 a new railway was commenced through the mountainous Semmering district in Austria to the south of Vienna. On some parts of the route the gradients were of the hitherto unheard-of steepness of 1 in 30. In order to obtain a suitable type of locomotive the directors, as in the case of the Stockton and Darlington Railway, offered a prize of 2400 ducats for the best engine. The successful engine was one called the Bavaria, which had all its wheels, not only those of the engine but also those of the tender, coupled together by means of endless link chains. In this way the necessary adhesion on the rails was provided, especially as the engine weight was unusually great. Satisfactory results were not obtained in actual service owing to the frequent breaking of the chains connecting the driving axles. Engerth dispensed with the chains, substituting toothed wheels on the several axles, in gear with one another. This arrangement also was abandoned after several trials. To overcome the difficulty experienced by the previous competitors of running their long, comparatively rigid engines round sharp curves, Fairlie designed an engine in which two boilers, placed end to end with the fire box between, were used. The front part of the engine was carried upon a bogie, the central pivot of the bogie being placed under the middle of the boiler. A similar bogie arrangement was used under the other boiler, and in this

way provision was made for some relative motion between the boiler and the engine frame, so that curves could be more readily passed. Upon each bogie two cylinders with all the necessary gear were fitted, so that the locomotive in reality consisted of two placed end to end with the boilers in one rigid piece. Though Fairlie's engine effectually surmounted all the previous difficulties at sharp curves, it was at the expense of much complication, especially in the arrangement of the steam pipes between the boiler and the cylinders, which were provided with spherical joints and sliding pieces to give the necessary flexibility. A very similar engine, the Petiet, was built by the Company du Nord. It comprised essentially two engines and two boilers, each engine having two cylinders and three driving axles. A joint was provided between the frames to allow them to move as required when rounding curves. At the present time this arrangement is no longer used, excepting in special cases where the route has sharp curves and heavy gradients, and the locomotive requires to be exceptionally powerful, as for mountain-railway work. An example of these articulated locomotives is illustrated in the plate facing page 164.

In 1851 a new competition was announced, but the results were of but little actual value. From 1851 onwards many improvements were effected in the details of the locomotive. One of the most important of these was the Injector devised in 1856 by the French engineer Giffard for supplying feed water to the boiler.

Only a very rapid survey of the history of the locomotive has been attempted, as the intention of this work is to deal more with the present than the past.

CLASSIFICATION OF LOCOMOTIVES

Until recently there was no general classification of locomotives into definite types. Each country distinguished its engines in different ways, either by a brief description of the arrangement of the essential parts, the cylinders, and the axles, or by giving the types more or less fanciful names, which conveyed no idea of the character of the engine itself. In America, for example, this system of nomenclature gave the well-known Atlantic or Chautauqua, Columbia, Prairie, Mogul, Consolidation, and numerous other types.

The system of classification first used in America, and now in this country, is much more direct and self-explanatory. Its adoption in other countries is becoming more general, due possibly to the increasing similarity in locomotive design both at home and on the Continent. It is based upon the arrangement of the wheels, which are divided into three groups, comprising, first, the leading carrying wheels; second, the driving wheels; and third, the rear or trailing wheels at the fire-box end of the engine. Each of these groups is distinguished by a number, which indicates the number of wheels in the group, and the three numbers together in their correct sequence give complete information regarding the number of driving wheels coupled together, the arrangement of the front wheels, and whether one axle is used or whether the forward end is carried upon a bogie.

A list of the types in most general use is given on p. 131. In the first column the wheel arrangement is diagrammatically indicated. The second column gives the number of the wheels in each of the three groups, while the third column contains the American name under the old system.

Each type may again be subdivided in accordance with differences in the arrangement of other parts. The engine may, for example, have a separate tender or be of the tank type, or again it may have single-expansion cylinders or be compound. Such details do not in general characterize the engine so completely as does the wheel arrangement. Upon the Continent the system is not so completely carried out as in this country or America. Only two numerals are used, the first to represent the number of coupled axles, and the second to indicate the total number of both carrying and

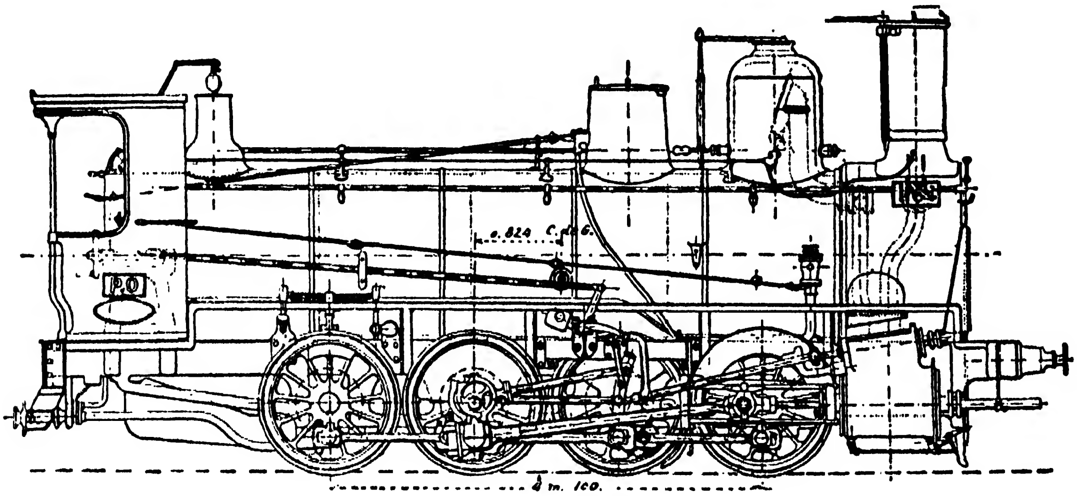
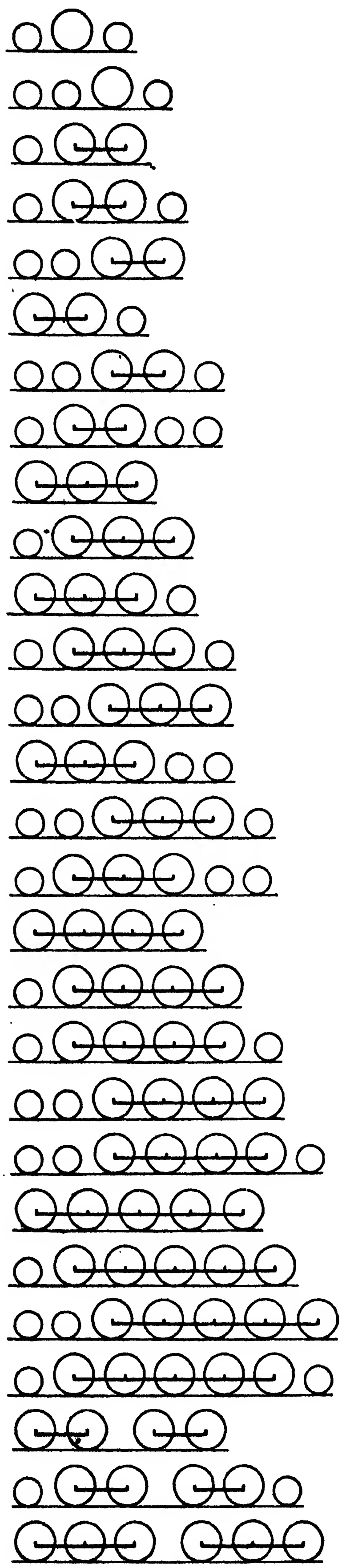


Fig. 153.—French Goods Locomotive, Orleans Railway

driving axles. In the one system an engine with four driving wheels and carried at the front end upon a four-wheeled bogie, but unsupported by any wheels at the fire-box end, would be indicated by the numerals 4–4–0. In the other system the numerals 2–4 alone would be used, the 2 indicating the two coupled driving axles, and the 4 the total number of axles. This second arrangement gives no clue as to whether or not a bogie is used, and states nothing regarding the arrangement of the axles, beyond giving the total number and how many of them are coupled as drivers. For these reasons the Continental system is being gradually superseded by the American.

From the length of the list, which includes only the most typical arrangements, it will be evident that there is endless variety in the design of locomotives, even in this one feature of the arrangement of the wheel base. Superintending engineers are compelled by the special features of their lines and the nature of the traffic to build locomotives that will best meet the requirements, and on any particular system it may be necessary to develop several types for the efficient working of different sections of the line and traffic. There is apparently a growing tendency on the part not only of individual railway companies, but also of the British, American, and the Continental companies, to arrive at types of greater uniformity, and to reduce as far as possible the number at present in service. On the Continent more attention is being paid to external

Diagram of Wheel Arrangement.



Notation.	Description.
2–2–2.	Six-wheel single driver.
4–2–2.	Leading bogie, single driver.
2–4–0.	Four-coupled.
2–4–2.	Columbia type.
4–4–0.	American or Eight wheeler, four-coupled.
0–4–2.	Six-wheeled, front-coupled.
4–4–2.	Atlantic, four-coupled drivers, leading bogie and two trailing wheels.
2–4–4.	Four-coupled trailing bogie.
0–6–0.	Six-coupled.
2–6–0.	Mogul.
0–6–2.	Six-coupled radial trailer.
2–6–2.	Prairie type.
4–6–0.	Ten-wheeled, six-coupled bogie.
0–6–4.	Six-coupled trailing bogie.
4–6–2.	Pacific type.
2–6–4.	Six-coupled trailing bogie.
0–8–0.	Eight-coupled.
2–8–0.	Consolidation.
2–8–2.	Mikado or Calumet.
4–8–0.	Eight-coupled leading bogie.
4–8–2.	Dübs type.
0–10–0.	Ten-coupled.
2–10–0.	Decapod.
4–10–0.	Mastodon.
2–10–2.	Santa Fé.
0–4–4–0.	Articulated locomotive.
2–4–4–2.	Articulated locomotive.
0–6–6–0.	Mallet and Fairlie types.

appearance than has hitherto been given, while in Britain the frequent adoption of the Walschaert valve gear has helped to reduce in a marked degree the very dissimilar outward appearance of locomotives built in these two countries. British railway engineers, in contrast to those of other lands, still place great importance on the neat outward design of their locomotives, and their example is being more generally followed by foreign engineers. A comparison of the following figures will illustrate the improvement that is taking place. Fig. 153 is a goods locomotive in service on the French Orleans railway, and fig. 154 is a passenger locomotive of the Chemin de fer du Nord. Fig. 155 shows a shunting locomotive of British design built by Messrs. Barclay & Co. of Kilmarnock, and fig. 156 illustrates a goods engine recently produced by Messrs. Borsig of Berlin for the Anatolian Railway Company. In its design considerable attention has apparently been paid to outward neatness.

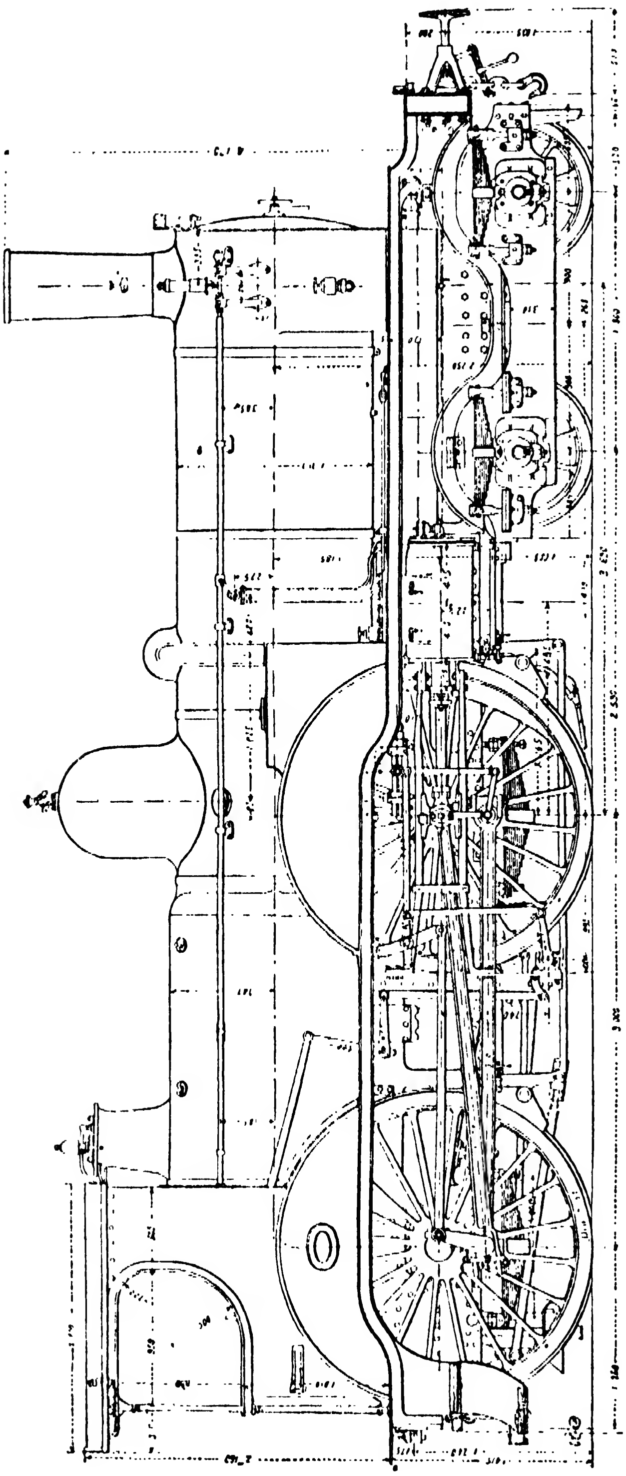


Fig. 154—Passenger Locomotive, Chemin de fer du Nord

In determining the type of locomotive best suited to any particular railway, the conditions of the service must all be carefully considered. A locomotive built for service in America, and well suited to the conditions existing there, would not probably run well on a British railway. In America the coal is frequently of inferior heating power to the coal used here, necessitating a larger grate and fire box, more boiler heating surface, and other special arrangements. This is particularly the case when, as often happens, wood is the only obtainable fuel.

On most railway systems the traffic may be roughly divided into two classes—goods and passenger. For the former, heavy engines capable of drawing very heavy train loads

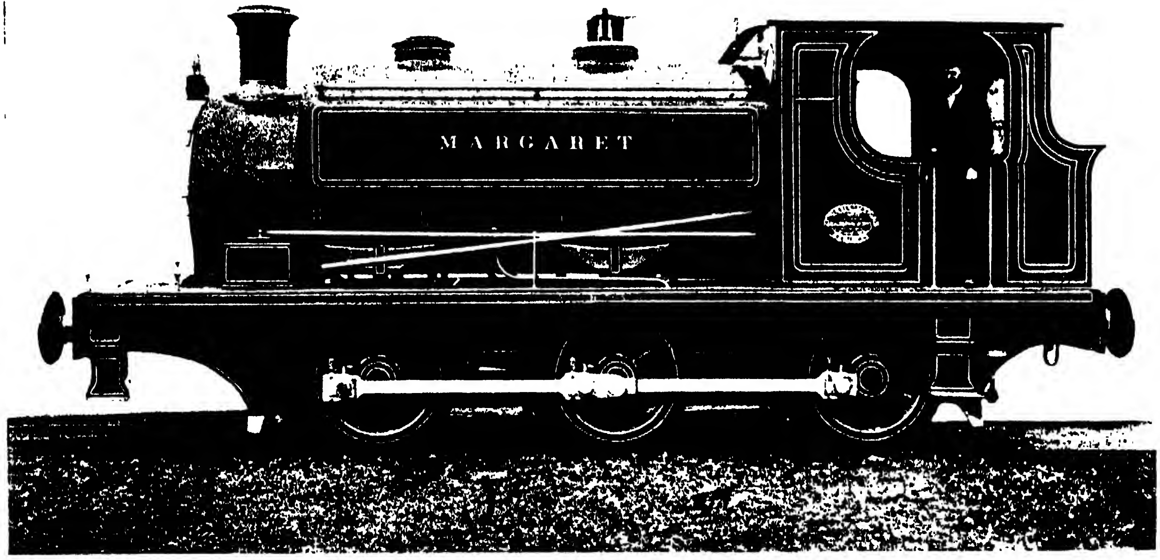


Fig. 155.—Shunting Locomotive by Messrs. Andrew Barclay, Sons, & Co., of Kilmarnock

are necessary, but the speed need not exceed 10 to 12 miles an hour. Goods engines have generally several or all of their wheels coupled together, in order to obtain sufficient adhesion upon the rails for the traction of the load, which on some American roads is

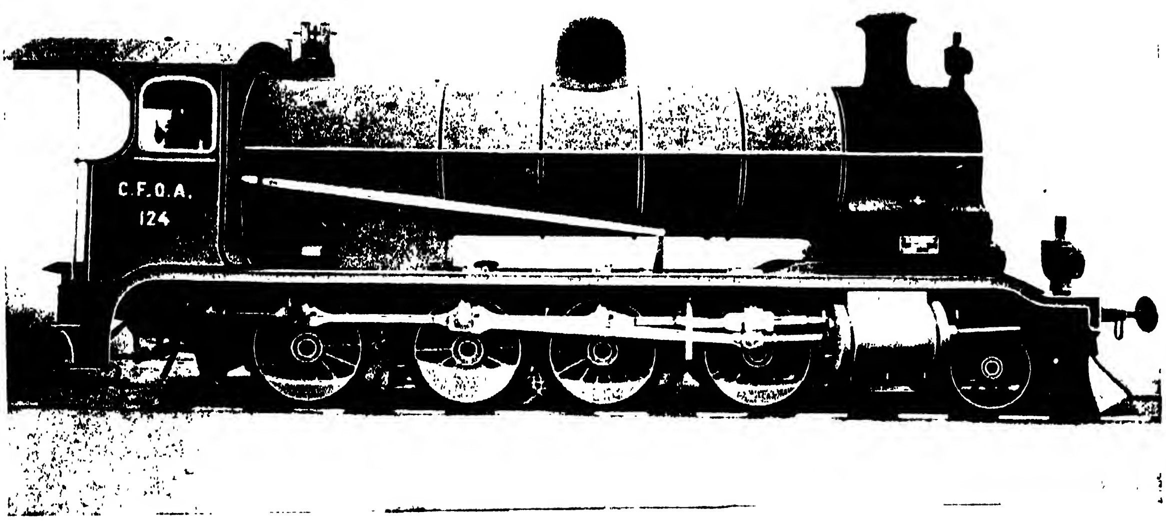


Fig. 156. Goods Engine constructed by Messrs. Borsig of Berlin for the Anatolian Railways

as much as 2000 tons. For passenger traffic, on the other hand, the first essential is speed, although often the loads are by no means small, as in the case of the principal express trains running between London and the North. Another cheaper

and smaller type of locomotive is best suited to local passenger traffic, where stops are frequent and the running not so continuous. It will be evident from what has been said that the nature of the traffic is one of the principal factors in the choice of the most suitable type for any particular road.

Although the tendency is towards the reduction of existing types, there is still too great a variety to make a general classification possible, particularly when account is taken of mechanical details. It is not possible, therefore, to do more than give a very general classification, as follows:—

1. Heavy goods.
2. Heavy express passenger.
3. Mixed traffic, light goods or passenger.
4. Narrow gauge and contractors' engines.

These, again, might be subdivided into other classes. The tender might be separate from the engine, or carried on the same frame as in the case of tank engines, or again, the expansion of the steam might be on the compound principle or on the single; but so far as the present work is concerned, the above simple classification, which is based more on the wheel arrangement than on the mechanical considerations, will satisfy the requirements.

Heavy goods engines are required to exert the greatest possible tractive force, but do not need to run at any but comparatively low speeds. Considering the restrictions imposed on designers of locomotives, it is not practicable to provide more than a certain power, so that increase of tractive force can only be obtained by some sacrifice of speed. Engines of this class have a characteristically heavy and massive appearance, owing to the weight required to give sufficient adhesion on the rails. For the same reason the driving power is distributed over several or all of the wheels by means of connecting rods, or, in the case of compound or multiple cylinder engines, by directly driving several of the wheel axles.

Fig. 157 illustrates diagrammatically the arrangement of one driving wheel and the forces acting upon it. As the journal of the wheel is the part carried by the engine frame, to which the load is coupled, the tractive force may be considered as acting at the level of the axle.

If P be the tractive force,
R the radius of the wheel,
r the length of the crank,
and Q the total mean driving force exerted by the pistons, then
the tractive couple P R = the driving couple Q r,

$$\text{and } P = \frac{Qr}{R};$$

that is, the tractive force P may be increased by increasing the driving force Q, or the crank length r, or by decreasing the diameter of the wheel. Other considerations limit

the values of Q and r, so that to obtain the required pull, the wheel diameter must be decreased. To increase Q it would be necessary to increase the boiler pressure, but this cannot be raised much beyond 200 to 228 lb., especially considering the present large boiler diameters. In locomotive practice, boiler pressures vary in the case of large engines from 150 to 200 lb., though pressures up to 228 lb. are in use, especially on the Continent. If the area of the piston were increased the value of Q would be correspondingly raised, and at the same time the volume of steam per stroke. This would, however, involve an increase of the boiler capacity, which already has almost reached the limits imposed by the loading gauge. By increasing the crank arm r the value of P may be raised, but here again there are certain practical limits, for since the piston stroke is determined by the length r of the crank, the piston speed for a certain train speed would be correspondingly increased. In ordinary engine practice, piston speeds of 500 ft. per minute are considered quite sufficient, but in the locomotive, piston speeds of double this amount are common. In this direction there is not much room for further advance, and the remaining solution of the problem, the decrease of the driving wheel diameter R, is the one generally adopted. Comparison of the heavy goods engine (fig. 156) and the express passenger engine (fig. 154) will make clear the difference in the driving-wheel diameters. From the above it will be evident that the determining factor in the development of the locomotive is ultimately the boiler. At the present time the boiler is of sufficient capacity to meet, when forced, even the heaviest demands, but if the demands grow as rapidly as in the past, the provision of sufficient steaming power in one engine will be a most difficult problem.

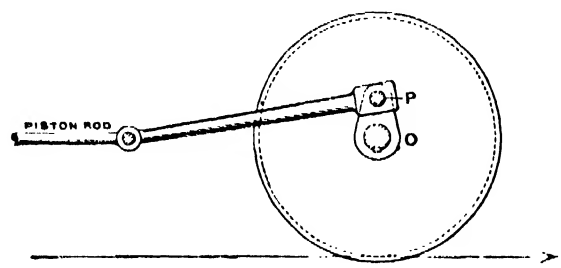


Fig. 157

The actual load that the engine can draw is determined by the adhesion between the driving wheels and the rails. When the load is increased a point is reached at which the wheels fail to grip, and rotate idly. Under these conditions the load equals, or rather just exceeds, the force due to friction between the wheels and rails — that is, the tractive force P = the pressure W on the rails, multiplied by the coefficient of friction for the two materials of which the tyres and rails are made. If μ represents the coefficient of friction, then $P = \mu W$, which shows that to increase the tractive force the adhesion weight W must be increased by concentrating more of the weight over the driving wheels. It should be noted that the value of μ will vary according to the weather conditions. With dry rails the adhesion will be greatest, and μ will have a value of about 0.3, while with oily rails, or under the still worse conditions of frost, the value of μ may fall as low as 0.1.

In practice, locomotive designers hesitate about placing on any one axle a greater load than 19 tons, as heavier loads rapidly destroy the track. Single-driver engines, which until quite recently were greatly favoured in this country, often had to carry this extreme load, but in the case of coupled drivers the main axle loads do not exceed 8 to 9 tons. Instead of attempting to concentrate the greatest possible weight

upon one driving axle, as in the case of single drivers, the universal present-day practice is to distribute the weight over several axles, the number depending on the adhesion required, and to couple these wheels together so that each takes a portion of the drive. As the load is increased the number of driving axles and coupled wheels must also be increased, to obtain the necessary adhesion with a reasonable distribution of the weight. In America, where the train loads are much in excess of those possible in this country, the coupled engine has been carried to a state of high development, and engines with ten-coupled wheels are in common use for the heavier classes of traffic. Until recently the single-driver locomotive was the type universally favoured by British engineers, although on the Continent and in America it never obtained any practical hold. On several of the larger railways the type was tried, but never adopted, on account largely of differences in the traffic conditions; and now in this country also the train loads have increased beyond the power of the single-driver locomotive, in which not more than 19 tons adhesive weight is available on the driving axle. A common wheel diameter for the single-driver type of locomotive is about 93 in., but this has been exceeded in the case of the Great Northern Railway engines designed by Mr. P. Stirling, in which a driving-wheel diameter of 97 in. is adopted with a view to attaining high speeds. This may be taken as the higher limit of wheel diameter. In the case of express four-coupled engines the wheel diameter varies from 78 to 82 in., according to the requirements and to the design of the engine. As the boiler cannot be raised above a certain height, fixed by the loading gauge, the size of the wheels is really determined by the boiler diameter and by the fact that the wheel axle must pass under it with sufficient clearance, when inside cylinders are used, for the cranks and valve motions. Goods engines of the six-coupled type have, in general, wheel diameters of about 60 in., and in the case of eight-coupled engines 54 in., depending always upon the kind of engine and the nature of the working conditions to be satisfied. The present lower limit of wheel diameter may be taken as 57 in., as in the heavy Decapod type of American goods engine, with the exception, perhaps, of certain of the articulated locomotives.

Having determined the proportions of the speed and the tractive force, the next important point is the question of smooth running, especially round curves. The distance between the extreme axles is called the wheel base, and the distance over the axles that are coupled together is the rigid base. To ensure smoothness of running it is necessary that this rigid base should be reduced as far as the conditions permit, and that some provision should be made for a certain amount of play between the engine frame and the leading and trailing wheels, that is, the wheels before and behind the coupled drivers. There are several ways of providing this flexibility, one or more of which may be adopted, but frequently in the case of other than express engines there is sufficient space between the wheel flanges and the rails to permit of the required side play. Fig. 158 shows a pair of carrying wheels on rails of the standard gauge, 4 ft. $8\frac{1}{2}$ in. With a rigid wheel base of 16 ft. on a curve of 8 chains (about 530 ft.) the required side play would be $\frac{3}{4}$ in., which is well within that provided as indicated in the figure. In certain classes of slow-running engines no further provision is made, but in the case of passenger and express

locomotives the wear due to friction and the unsteadiness when running round the curve would be excessive unless additional flexibility of wheel base were provided.

To completely meet the requirements of smooth running round curves, the axles should have a certain side play and also a radial freedom, so that they may direct themselves towards the centre of the curve. At least the former should be allowed for, and both in the case of fast-traffic engines. Side play is sometimes allowed for by giving the axle boxes some freedom in the hornblocks. The wheels then move relatively to the frame by the necessary amount when passing over the curve.

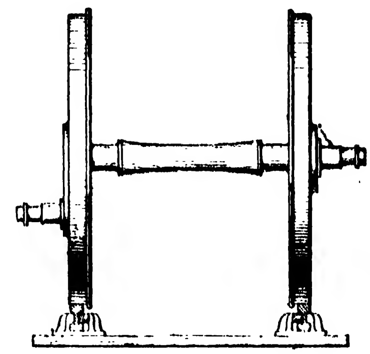


Fig. 158

The second method is the radial-axle system, which is carried out in a number of ways, and in most of these the axle boxes are so guided that they may move both radially and transversely. The third arrangement is the truck or bogie, which is almost generally adopted in the case of fast and heavy locomotives.

RADIAL AXLES

Webb's Radial Axle Box.—Mr. Webb devised the arrangement shown in figs. 159 and 160 for the engines of the London and North-Western Railway Company. It is fitted to the leading single axles of the express locomotives, and to both the leading and trailing axles of tank engines. Across the frames is fixed a pair of curved guides separated in the centre by a spring box, which serves also as a distance piece. The guides constrain the cast-iron axle box to move in a curved path about some point within the rigid wheel base, which may readily be determined according to

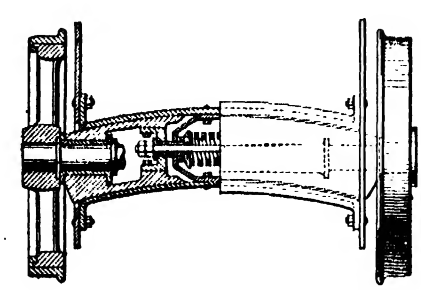


Fig. 159

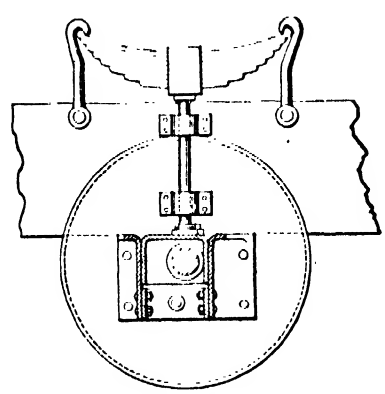


Fig. 160

the position of the axle and the nature of the curves to be traversed. In the illustration the axle is shown partly removed to expose the spiral springs, which control the motion and limit it to about $1\frac{1}{4}$ in. on either side. On the underside of the axle-box castings, projections are formed which engage with the ends of the springs. This is indicated in the sectional end elevation (fig. 160), which shows the axle situated above

the spring. This elevation also illustrates the method of carrying the weight transmitted through the bearing springs to the axle boxes. On the upper faces of the boxes are machined channels curved to the same radius as the axle-box guides, and in the groove are fitted sliding plates upon which bear the pins of the bearing springs. Frequently the channels are machined each with a slight upward inclination, so that the weight on the boxes tends to bring them back into the mid position after each displacement.

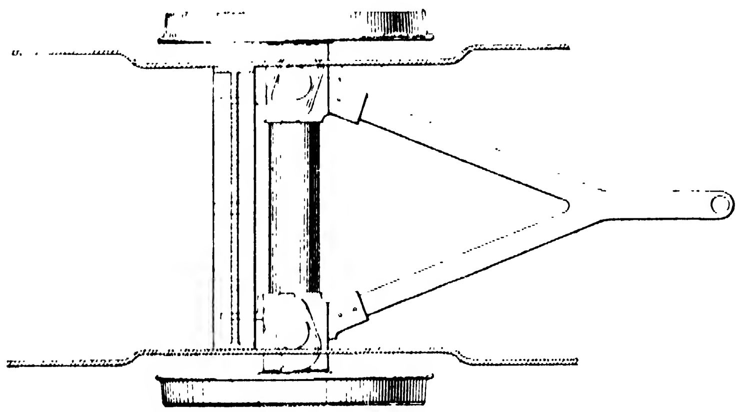


Fig. 161.—Pony Truck Plan

Worsdell's Radial Axle Box.—Two laminated springs are used in the Worsdell arrangement instead of the two spiral springs used by Mr. Webb, but otherwise there is little difference in the essentials of the two systems. Projections from the lower portions of the axle boxes bear as before against the buckles of the laminated springs, there being one spring to each axle box. The Worsdell radial box is largely used on the Great Eastern and the North-Eastern Railways.

The Pony Truck. For single axles the pony-truck arrangement is very frequently adopted. It consists of a triangular framework pivoted at the apex in the centre line of the engine. One side of the triangular frame is formed by a casting which acts as a guide for the axle boxes, while the other two sides are the ties which serve as radius bars. The whole framework with the wheels and axle is thus free to move about the pivot relatively to the engine frame, within, of course, the limits of the checking springs. On the upper side of the transverse frame and above the axle boxes are machined surfaces upon which the bearing spring pins work in a curve around the pivot. Across the engine frames are fixed two stays—one towards the middle of the engine to carry the pivot pin, and the other alongside the axle casting to carry the controlling springs and checks.

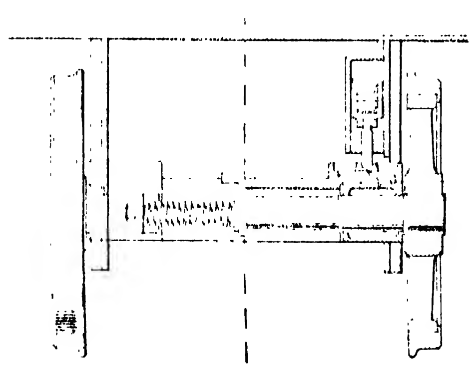


Fig. 162.—Pony Truck. H F Sectional End View

The arrangement of the parts as applied to one of the Great Northern Railway engines, designed by Mr. H. A. Ivatt, is shown in figs. 161 and 162. In the Bissell truck, which is largely used in America for single axles, the weight is transmitted to the axle casting by means of an equalizing beam, one end of which is fulcrumed on a suspending link hung from the engine frame, while the other bears over the axle. At some suitable intermediate point is applied the weight to be carried.

BOGIE TRUCKS

When greater flexibility combined with a suitable distribution of the axle weights is required, the bogie arrangement is adopted, unless in very special cases, when one bogie alone is used, either leading or trailing, according to the disposition of the driving wheels. Tank engines having a considerable wheel base are frequently fitted with both leading and trailing bogies, the latter being required to carry the weight of the combined tender. A bogie not only gives increased flexibility, but also allows of the weight being distributed more uniformly over the rails, and for this reason alone its adoption is often essential. As already stated, a greater load than 10 tons on any one axle is not desirable, owing to the nature of the permanent way, and in many cases this would be exceeded at the forward end of the engine if a single axle were used. By means

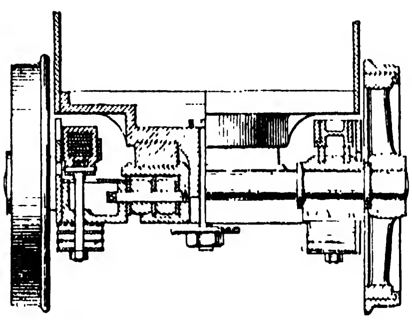


Fig. 163

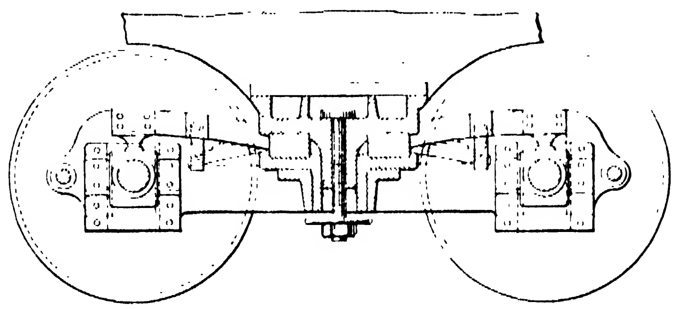


Fig. 164

of the bogie the weight is thrown more gradually upon the rails, with as a result increased smoothness of running and less general wear.

A typical design of leading bogie is illustrated in the figures 163 and 164, but innumerable other arrangements based on the same principles are in common use. The two axles are carried by a pair of small side frames fitted with ordinary hornblocks, in which the axle boxes slide with some vertical play. In the middle the frames are bound together by a large casting planed across the upper face, which serves as a seating for the sliding saddle piece and pivot. The cross slide, which is allowed some play sideways in the main casting, is also machined on its upper face, and bored out to take the turned boss which serves as the bogie pivot pin or trunnion. The bogie, therefore, pivots about the trunnion and at the same time is able to move sideways on the cross slide. Cradle beams, shown in the figure, transfer the weight from the side frames to the wheels. At the ends they rest upon the tops of the axle boxes, and in the middle on bearing springs, which in turn are suspended from the side frames. Side motion of the bogie is controlled by suitably placed springs. In the bogie illustrated, laminated side springs are used, but the arrangement varies in the different types. A centre pin, working loosely in a slotted hole, is also provided to prevent the cross slide and the pivot pin from rising off their seatings if the bogie at any time jumps. As the weight carried by the slide is considerable and the

movement is continuous, an efficient system of lubrication is essential, and the oil grooves on all the working faces should be of ample size.

American bogies are frequently made as shown in fig. 165, with suspending links in place of the cross slide. As before, the pivot attached to the engine body

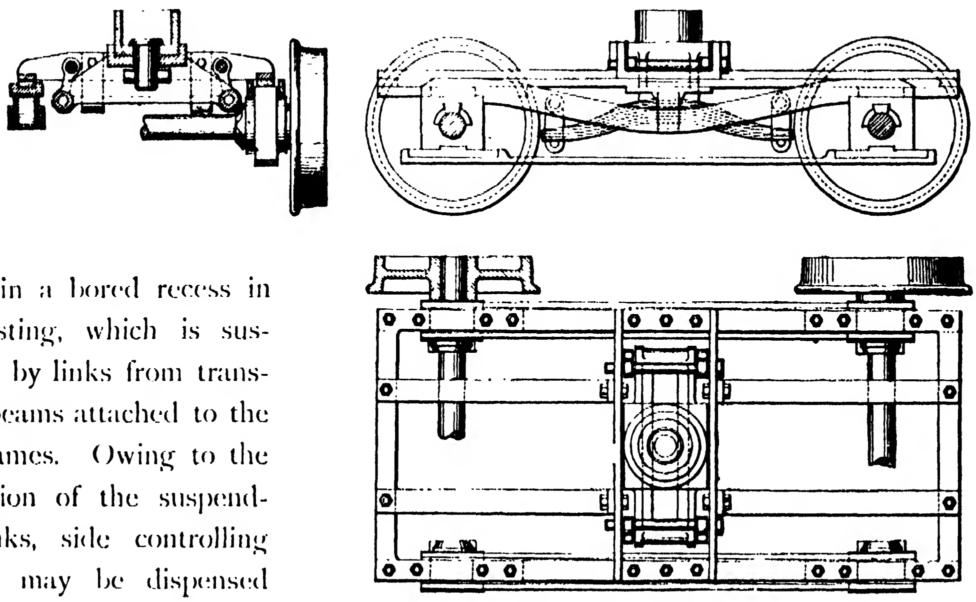


Fig. 165.—American Suspending-Link Bogie

works in a bored recess in the casting, which is suspended by links from transverse beams attached to the side frames. Owing to the inclination of the suspending links, side controlling springs may be dispensed with, the weight on the block being sufficient to prevent oscillation, and by increasing the inclination any desired control may be obtained. In many of the bogies devised by Continental builders the pivot pin is made spherical instead of parallel, and is suspended by links as described.

MAIN FRAMES

In the early days of locomotive engineering, the boiler was made to serve as the foundation upon which all the parts were carried, but the loads to be drawn were not great. As the size of the locomotive increased it was realized that means had to be adopted to protect the boiler from stresses, and accordingly a strong and rigid framework was provided to carry the boiler, engine, and wheels. All stresses other than those due to boiler expansion were thus confined to the frame and prevented from straining the boiler shell, which was attached at the front end only. From fig. 166, which shows in plan the arrangement of the parts, it will be seen that the side frames are connected rigidly at the trailing end by a heavy steel foot-plate casting, and at the leading end by the cylinder casting to which the smoke box is attached. At intermediate points the frames are bound together by cross stays consisting of steel plates set on end, and at the extremes by the buffer plates. At suitable points the side frames are cut away to take the hornblocks, in which the axle boxes have some vertical freedom and to a slight extent some side play, and wedges are generally fitted to take up slackness that may result from wear. In the case illustrated in the

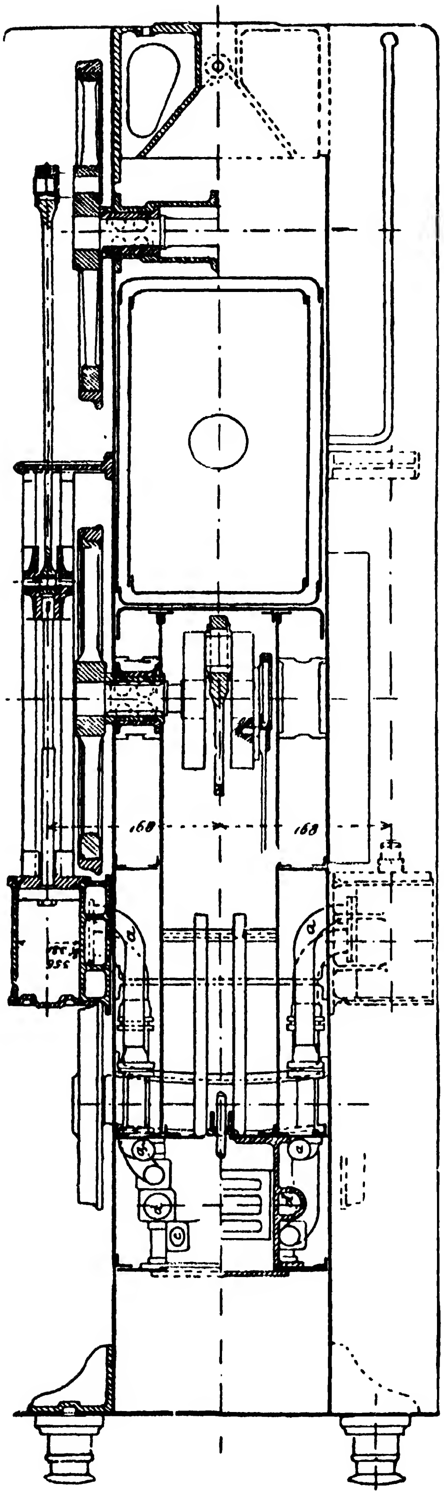


Fig. 166.—Three-Cylinder Compound Engine. Plan

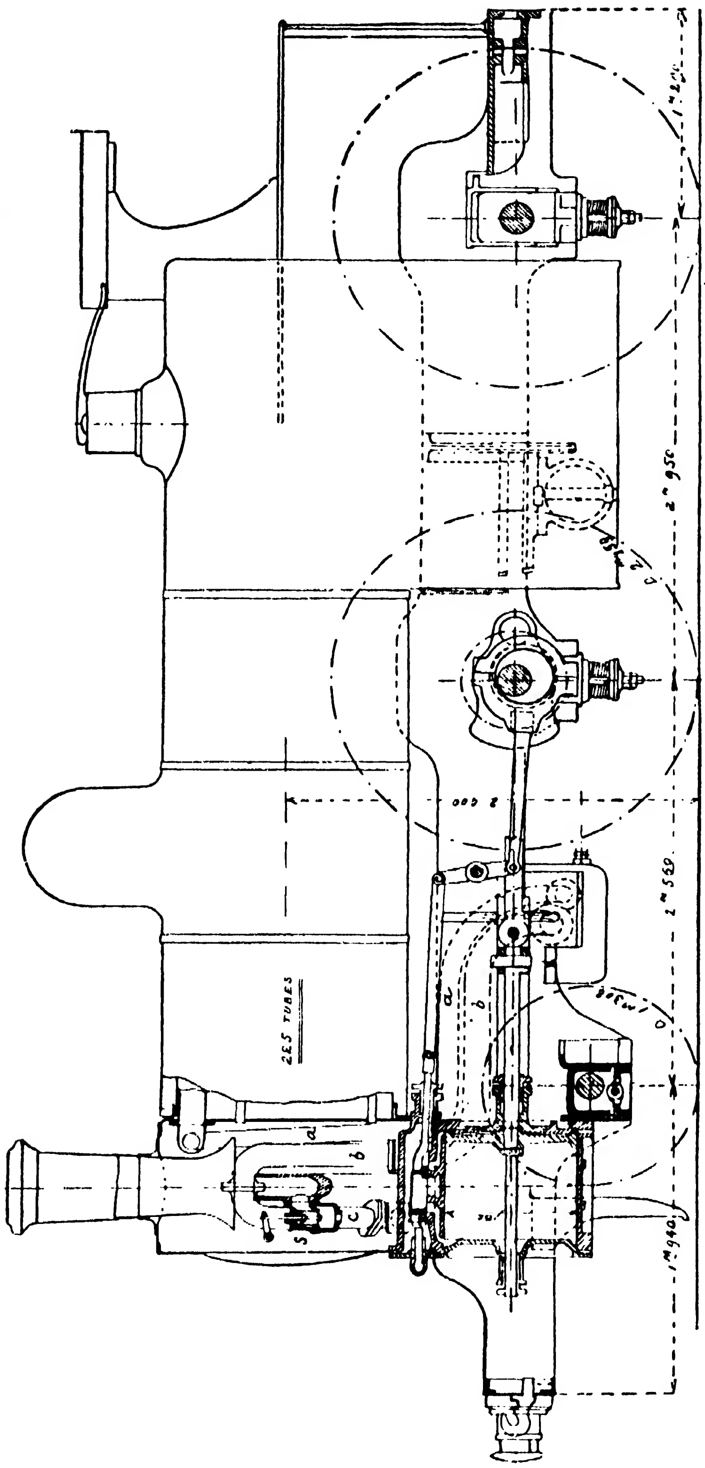


Fig. 167.—Three-Cylinder Compound Engine. Elevation

figure the interval between the driving wheels is made sufficiently great to clear the fire box, which is shown occupying the whole breadth between the frames but not touching them. A more common arrangement is to place the driving axles in front of the fire box, and behind it to place a trailing carrying axle, or a bogie if the engine is

of the tank type. The side frames may be inside the wheels or outside, or both inside and outside frames may be used together, as in the figure. British and Continental engineers make the side frames of continuous steel plates about $1\frac{1}{8}$ in. thick, but American engineers more frequently use a built-up arrangement of wrought bars and stays, as in fig. 168, especially for their long, heavy, freight engines.

Inside frames are generally adopted when the arrangement and size of the cylinders and of the fire box permit, but with a distance of only about 50 in. between the frames the space available for two 18-in.-diameter cylinders with the valve chest

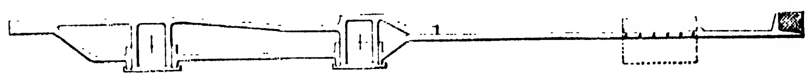


Fig. 168.—American Side Frame

between them is not more than sufficient. There is the same difficulty in arranging between the cranks the four eccentrics required for the two Stephenson link motions, and the width of the fire box is also restricted. Outside cylinders driving directly on to crank pins on the driving wheels are frequently adopted with inside frames, thus dispensing with the cranked axle and allowing the boiler centre to be lowered, as the valve motion is then quite clear of the boiler. In four-cylinder compound engines the inside arrangement of the frames is a very suitable one, since two of the cylinders may be placed between the frames and made to drive a cranked axle, while the remaining two placed on the outsides of the frames drive the wheels directly. Figs. 166, 167, and

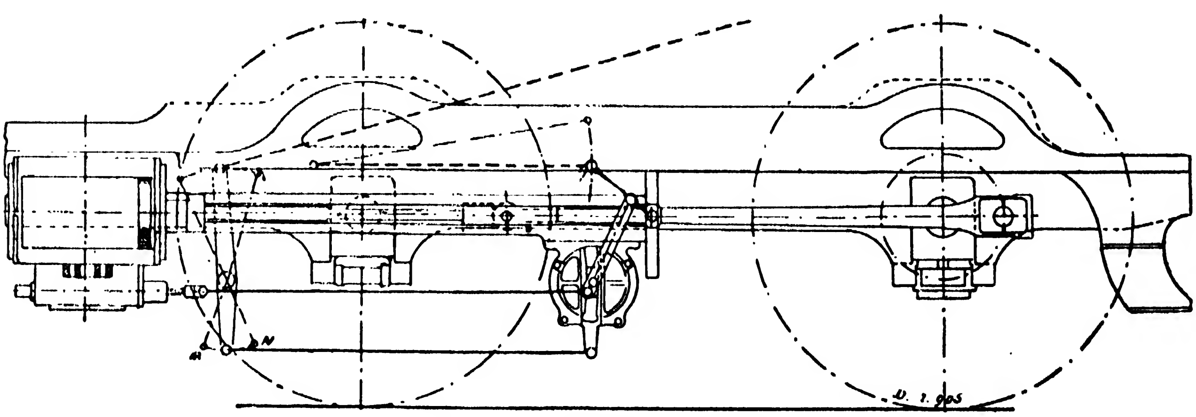


Fig. 169.—Arrangement of High-Pressure Cylinder Gear

169 show the plan and elevations of a three-cylinder compound engine in which the 30-in.-diameter low-pressure cylinder is placed between the frames and drives the crank of the leading driving axle, while the high-pressure cylinders are bolted to the outsides of the frames and drive directly the wheels of the trailing driving axle. A single eccentric radial valve gear controls the low-pressure cylinder steam distribution, and separate gears, shown in fig. 169, are provided for each of the high-pressure cylinders. The plan, fig. 166, shows also the double frames used between the forward cylinders and the transverse stays at the fire box to give a short distance between the main bearings of the crank axle. With such an arrangement of cylinders driving separate

axles, it is necessary to combine the driving efforts by coupling the wheels together, as illustrated. The single leading carrying axle is of the radial type already described.

Outside frames give more space for the fire box and for the inside cylinders and valve motions, but it does not permit of the wheels being driven directly when the

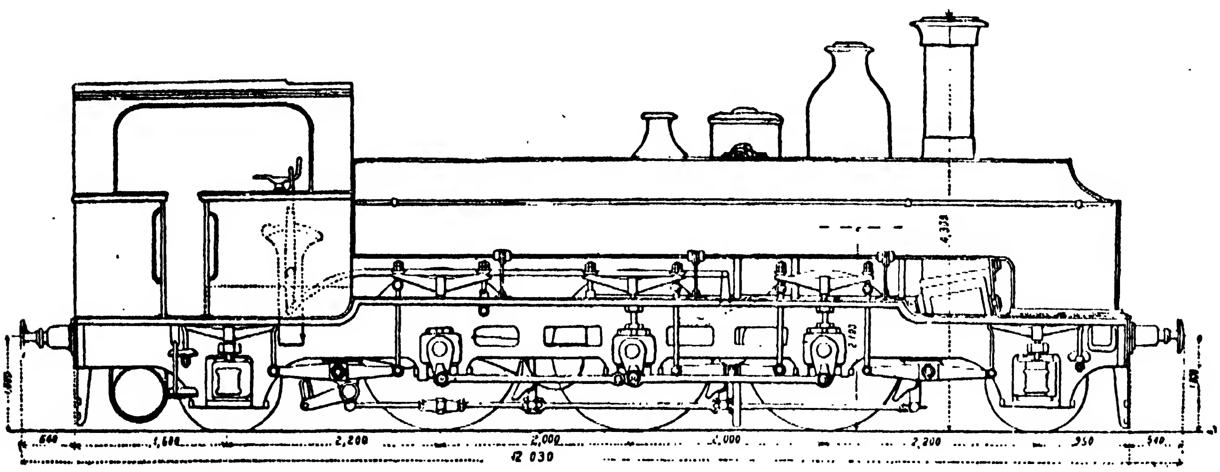


Fig. 170

axles are borne outside the wheels. It is necessary also to use return cranks for the coupling rods of the driving wheels. At the present time, locomotives with outside frames are never built, but one type used on the Belgium State Railways is illustrated in fig. 170. It has three-coupled driving axles with return cranks for the coupling rods.

BOILERS

For comparatively low powers the design of the boiler does not involve any great difficulty, but, owing to the limits imposed by the loading gauge, the case is very different when the power to be developed is great. Many of the present-day locomotives have already reached the limits of overall height, and further development must take place in other directions. In America, and certain parts of the Continent where the restrictions are not so severe, the adoption of large-diameter cylinders, with a consequently high power, is possible, as boilers of sufficiently large dimensions can be provided; but in this country, locomotive engineers must be satisfied with engines of less capacity. It has already been explained that the power developed in a steam cylinder is proportional to the quantity of steam consumed in a definite time and to the pressure. There are thus two ways of providing the required power, namely, by increasing

(1) The Pressure;
(2) The Cylinder Volume.

Boiler pressures of from 150 to 180 lb. per square inch are more favoured by British engineers than the higher pressures of 200 and 225 lb. These high pressures have

been adopted for certain of the Great Western and North-Eastern Companies' engines, but never so generally as on the Continent or in America. At pressures over 200 lb. there is experienced considerable trouble in keeping the stays and rivets tight, particularly around the large flat surface of the fire box. A low pressure of about 150 lb. is less severe on the structure of the boiler, and ensures a low maintenance charge. A high pressure of 200 lb. or more per square inch increases, on the other hand, the wear and tear, owing to the increase of both the pressure and the temperature. Notwithstanding the increased expense of upkeep which the high pressures involve, their adoption is frequently necessary in order to obtain the power without unduly increasing the capacity of the boiler itself, although the practice is not so general in this country as abroad.

An increase of the cylinder volume means an increase of the piston area, since the stroke is limited by such considerations as the limit of piston speed and the diameter of the driving wheels. Cylinder diameters of 18 to 19 in. for single expansion engines with strokes of 26 in. are most generally favoured for home railways, but locomotives for foreign service are frequently built with simple cylinders of 21 to 23 in. To supply sufficient high-pressure steam for two such large-diameter cylinders a boiler is required of larger dimensions than can be obtained under the limit of the existing British loading gauge.

In the example given above of a locomotive with two cylinders of 23 in. diameter, the boiler for a pressure of 200 lb. should have a heating surface of as much as 3500 sq. ft. British engineers have to be satisfied with about 2000 sq. ft. of total heating surface, although one of the large express engines designed by Mr. Worsdell for the North-Eastern Railway Company has a heating surface of 2400 sq. ft. for two cylinders of 20 in. diameter and 28 in. stroke. It will now be evident that the total cylinder volume is limited by the boiler steaming capacity, and that the boiler is primarily the factor which determines the power of the engine. No useful purpose would be served by providing large cylinders unless the boiler were correspondingly increased, and, as has already been shown, this is not possible beyond certain limits. The boiler should be sufficiently large to supply the cylinders with high-pressure steam under normal conditions of running, and should have, if possible, a further reserve of about 20 per cent of the steaming power, as experience has shown that continuous forcing results in excessive wear and increased cost of upkeep. Locomotive boilers require to work under more exacting conditions than any others, either on land or sea. Marine engines, or larger stationary land engines, usually work in conjunction with condensers, but in the case of the locomotive it would be quite impossible to carry the necessary condenser and pumps or to provide the cooling water. Expansion in the cylinder is therefore only carried to near the atmospheric pressure, and the remainder of the energy is partially utilized in the chimney in producing the required draught through the fire tubes. Figs. 171 to 182 show sections of an express passenger locomotive boiler, and details of certain parts of the structure. At the front end is placed the chimney and smoke box, and at the back the fire box. Between these is the barrel containing the groups of longitudinal fire tubes, through which the hot gases pass from the fire to the smoke box. On the top of the barrel in the highest position is attached a steam dome, from which the steam supply is drawn through the regulator.

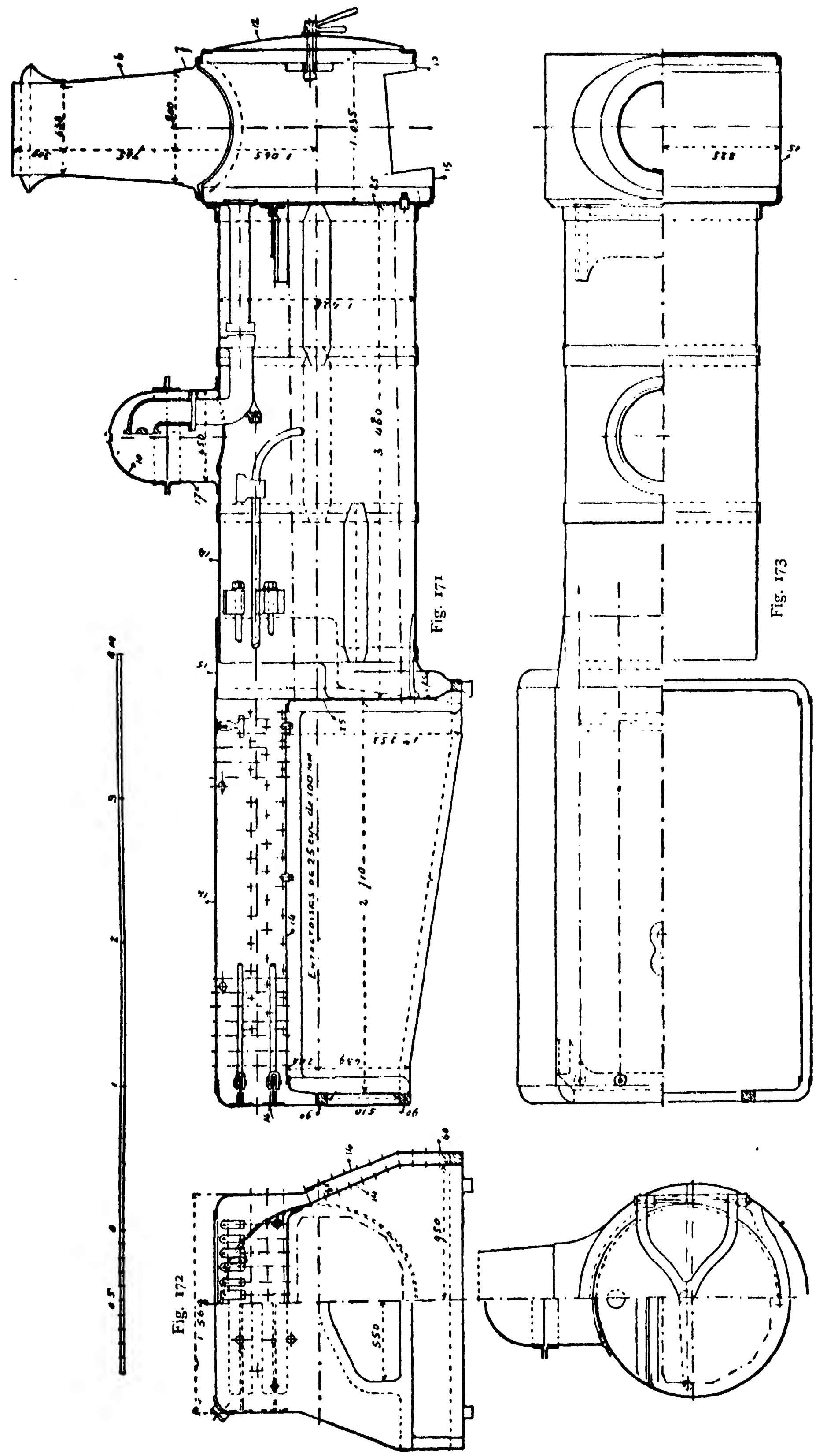


Fig. 171

Fig. 172

Fig. 173

Fig. 174

Wooten Type Fire Box

This ensures dryness of the steam supply to the cylinders; but in the heaviest types of express locomotives it has been found necessary to dispense with the steam dome, funnel, and other mountings, owing to the limit to the boiler diameter and to the height of the centre above the rails having been reached.

FIRE BOX

The inner fire box is attached directly around the base to the outer box or shell by a foundation ring, and at the fire hole by another ring, both rings being of the best Yorkshire iron. Copper is customarily used in this country for the inner fire-box plates,

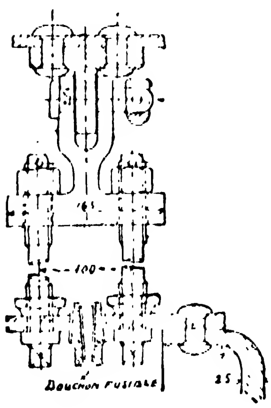


Fig. 175

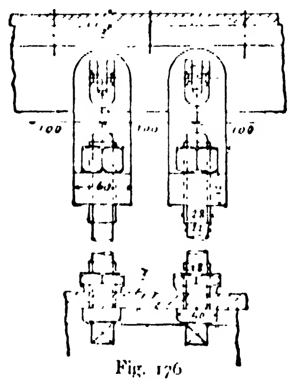


Fig. 176

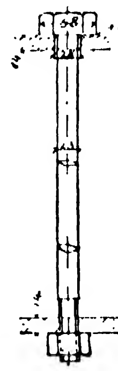


Fig. 177

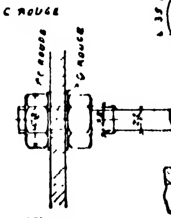


Fig. 178

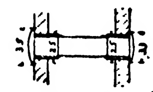


Fig. 179

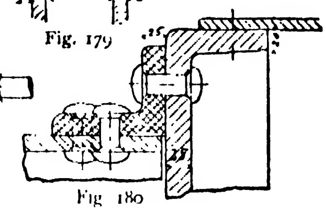


Fig. 180

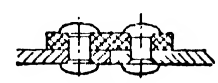


Fig. 181

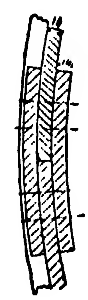


Fig. 182

with the outer shell of mild steel. American engineers, on the other hand, favour the all-steel construction, as, otherwise, differential expansion between the inside copper fire box and the outer steel shell is a serious trouble that must be carefully provided for. Both the fire grate and the ash pan have been omitted in the illustrations for the sake of clearness. The ash pan is provided with suitable air-supply dampers, controllable from the foot plate by hand levers. Water and steam spaces are formed around the sides and top of the inner box, and to prevent the large flat surfaces from collapsing under the high steam pressure, the inner plates are tied to the outer by numerous stay bolts and ties (figs. 175, 176, 177, and 179). Suitable tie bolts (fig. 178) are also provided to relieve the pressure on the boiler end plate. In the illustration two of these longitudinal ties are shown connected at one end to the end plate, and at the other to the first ring of the boiler barrel. Owing to the continuous changes in the relative expansion of the two boxes, excessive rigidity is to be avoided by some flexible arrangement of the stay rivets. In some cases the shank of the rivet between the surfaces is necked down to give the required flexibility, and in other cases slots are cut from the surface to the centre. Both methods are illustrated in the figs. 179 and 183.

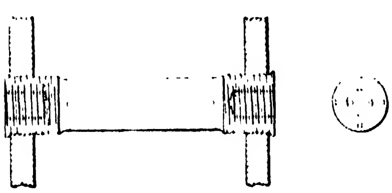


Fig. 183

Above the fire box it is essential to have a large water space as free as possible from obstructions that might hinder the circulation of the water over the plates most severely acted upon by the fire. Effective staying of the flat crown plate is therefore more difficult than in the case of the sides, and special methods must be

adopted to suit the particular design of the fire box, which may belong to one of three general classes:

1. Crampton.
2. Belpaire.
3. Wooten.

In the **Crampton type**, the top of the outside fire box consists of a curved extension of the cylindrical boiler shell, that is, the top of the box is continuous with the barrel, although there are cases in which the top is higher than that of the boiler. One continuous plate, called the wrapper, usually forms both the top and the sides, which are generally pressed in sufficiently to clear the frames. This arrangement

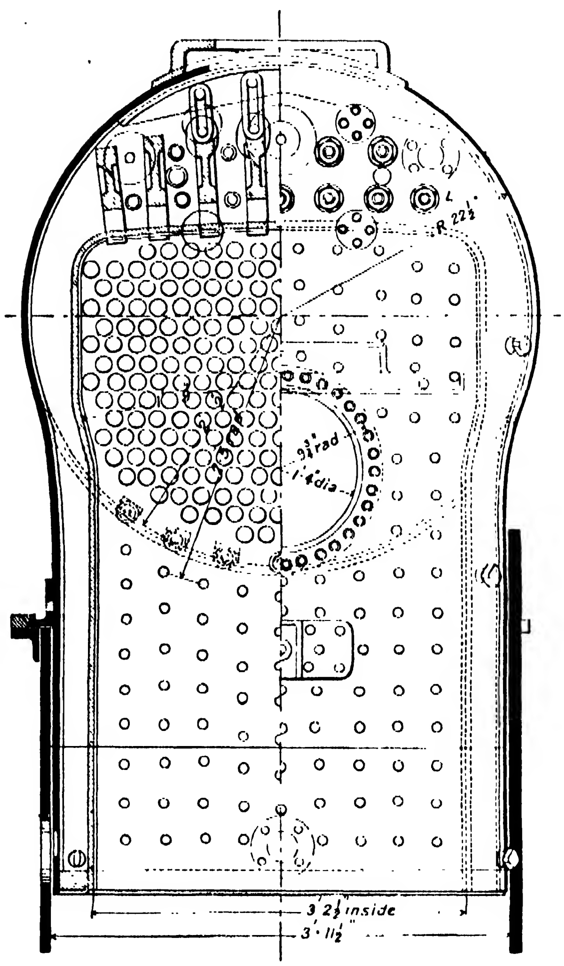


Fig. 184.—Crampton Fire Box

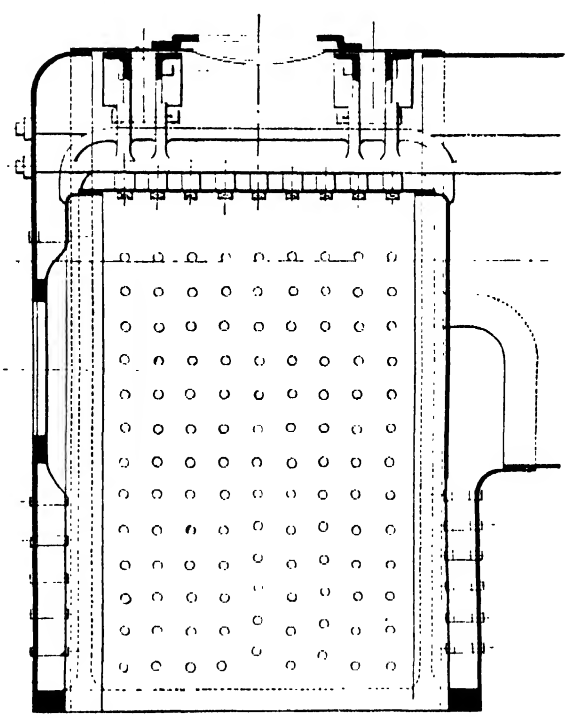


Fig. 185. Steel Fire Box

gives a comparatively narrow grate with a considerable height above the bars. Direct rivet stays (figs. 184 and 185) are used to bind together the flat sides of the inner and outer boxes, but it is not practicable in the same way to stay the flat top of the inner box to the curved crown of the outer, and some less direct means of support has to be provided. In the figures the cast-steel bearers adopted for the purpose are shown. Several of these longitudinal bearers are arranged side by side over the fire-box top with their ends resting upon the front and back plates, and from them the roof is supported by screwed bolts. The bearers themselves are frequently suspended at the middle by links attached to angle irons on the inside of the curved outer crown.

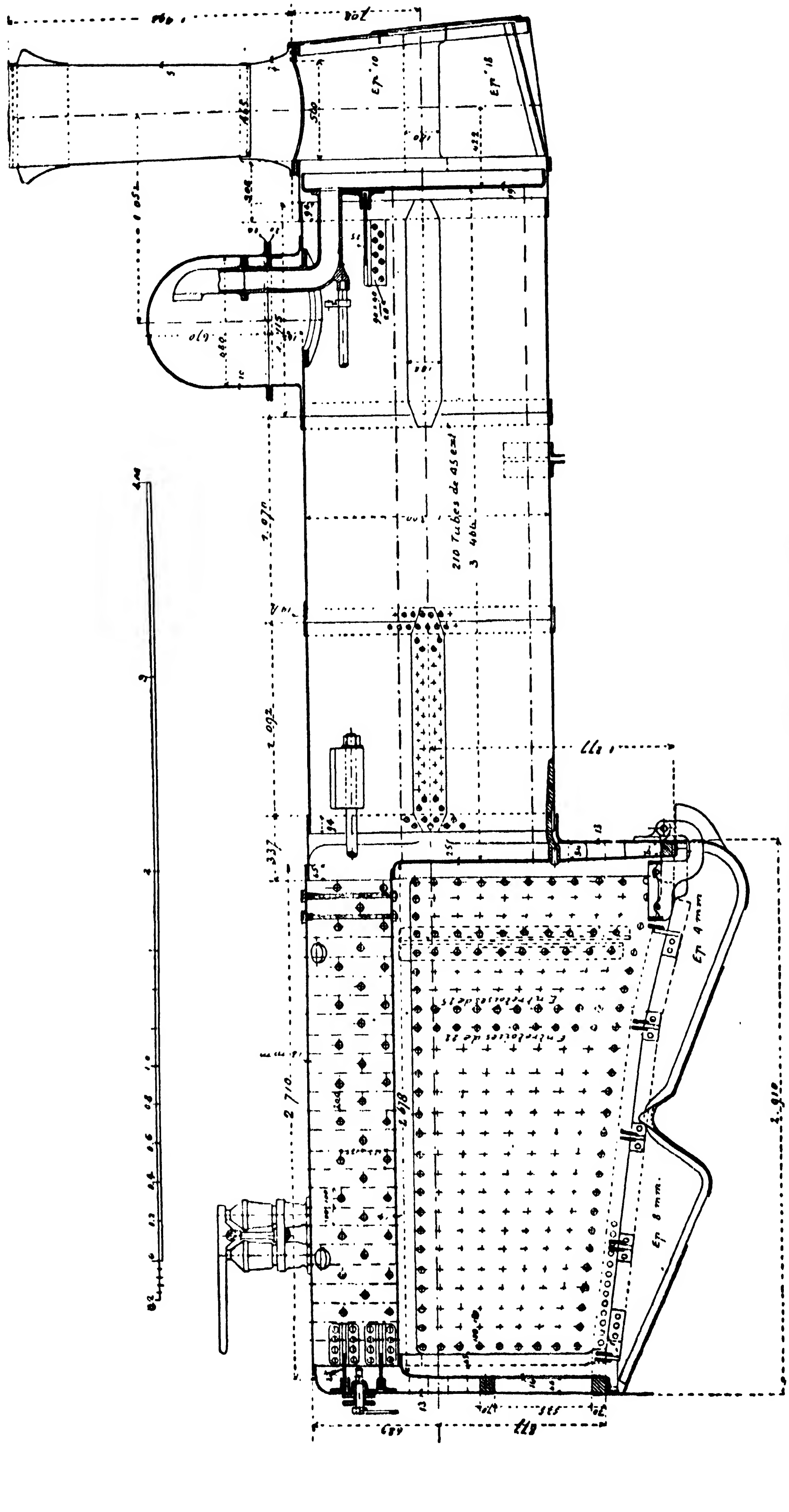


Fig. 186.—Section of Boiler and Belpaire Fire Box

Belpaire Type.—Many locomotive boilers are now fitted with fire boxes of the Belpaire pattern, on account chiefly of the freer circulation and the more direct staying that are obtainable. From figs. 186, 187, 188, and 189 it will be seen that the box differs from those of the Crampton type in having a flat outer wrapper, not continuous with the barrel of the boiler, which permits of the inner box crown being directly stayed from the outer, and dispenses with the heavy and expensive bearers. Apart from the advantage of direct staying, the water and steam space is more ample, the circulation over the surface is freer, and there is less difficulty in removing accumulations of scale. On the other hand, the flexibility of the direct-stayed arrangement is not so good, and difficulty is often experienced through leakage at the tube plate caused by excessive rigidity at the crowns. To overcome the objection, the rows of bolts nearest the tube plate are sometimes made of an articulated form that will permit of some relative expansion. Instead of the continuous outer wrapper used in the Crampton system, the Belpaire box has generally a separate crown plate, which makes repair a less expensive operation. The sides of the box are then formed of separate plates riveted to a front throat ring and to the back plate as before. Transverse bolts bind the flat sides of the outer box together, as shown in the end view of the arrangement (fig. 187).

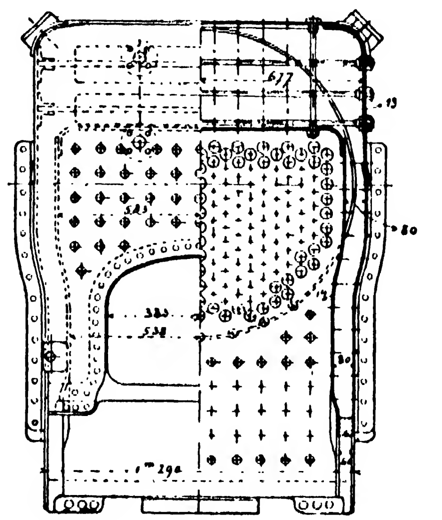


Fig. 187.—End Section of Belpaire Box

Wooten Type.—On foreign railways, where the heating value of the fuel is not great, as, for example, when wood is burned on the grate, and in America, where the boilers required for the heavy freight traffic are of unusual size, it is necessary to provide a larger grate area than can be placed between the frames. In fire boxes of the Wooten type the grate is placed above and extending over the frames, as shown in fig. 172, with the ash pan occupying the space between them. As in the Belpaire arrangement, the inner crown plate is directly stayed from the outer, with the rows of stays nearest the tube plate articulated, as shown in figs. 174 and 175, to relieve the stresses resulting from relative expansions of the plates, and the sides are tied together by rivet stays of copper, or sometimes of steel. In the illustration, fig. 172, only one fire door is shown. The great width of the grate in many cases necessitates, however, the provision of two doors to facilitate the work of the stoker.

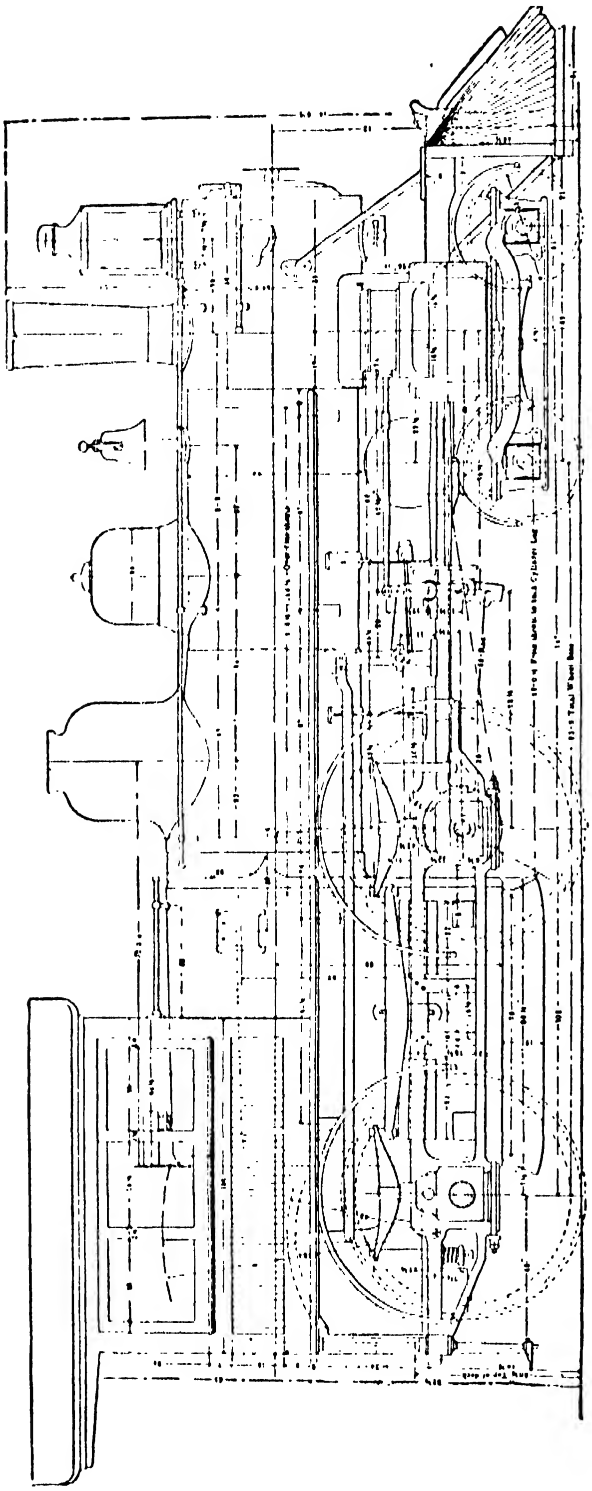


Fig. 188

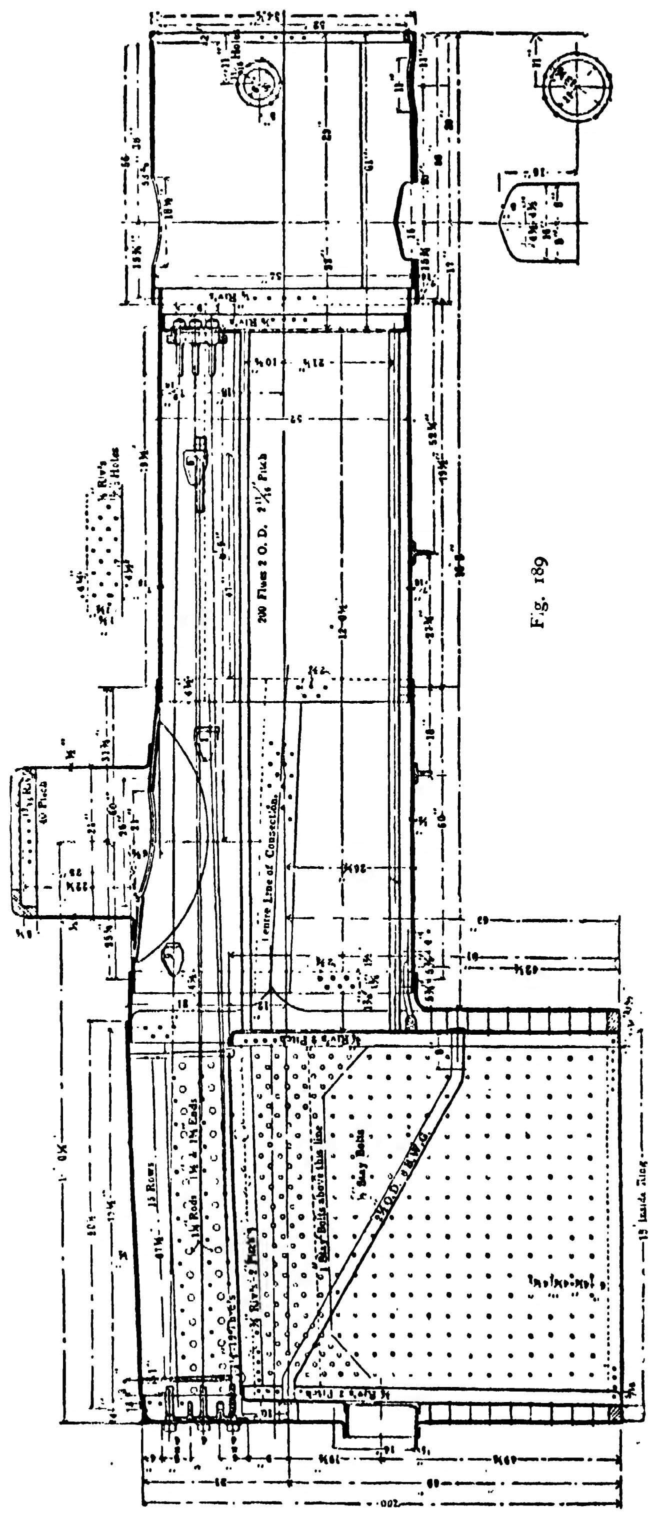


Fig. 189

THE BARREL

The boiler barrel is built up of two or three rings of mild-steel plates riveted together circumferentially and longitudinally, and attached at the front end by means of a shrunk on flanged ring to the tube plate, and at the back to the flanged end plate. Both end plates are stayed by long tie bolts to the barrel ring plates, in addition to the fire tubes, which also help to bind the boiler together in the longitudinal direction.

As the hottest and most efficient part is immediately over the fire box, it is desirable to make the water and steam spaces there as large as possible. With this in view, American engineers frequently make the first barrel ring of a conical shape, with the larger end at the fire box (fig. 189). This kind of boiler is known as the Wagon type. In this country the practice has been very largely adopted by the Great Western Railway Company, who are fitting it to all classes of their locomotives. It is called the coned or taper boiler, although essentially it is the same as the American Wagon type.

FIRE TUBES

In a well-designed boiler the steaming power is practically determined by the total heating surface of the fire box and tubes provided, when the grate area is of sufficiently ample dimensions to suit the quality of the fuel. A large heating surface does not, however, always mean a large power, because the increase of surface may be at the cost of other requirements; for example, the heating surface of the tubes may be increased by reducing the diameter and increasing their number, but this, if carried too far, would seriously reduce the water space and thereby increase the danger of the tubes becoming externally silted up, with a consequent loss of evaporative efficiency. Increased surface might also be obtained by lengthening the tubes, but, apart from mechanical considerations, the value of the added surface at the smoke-box end beyond a certain point would not be considerable, owing to the low temperature of the gases there and to the general reduction of the draught. On the Continent, frequent use is made of Serve tubes, in which the metal surface in contact with the gases is increased by means of internal longitudinal ribs; but notwithstanding the apparently favourable results that have been obtained, the use of Serve tubes has not extended in this country. The boiler illustrated in fig. 186 is of French design, and is fitted with Serve tubes of the section shown in fig. 190. Other attempts have been made to increase the heating surface by fitting water tubes at the place where the gases are hottest, that is, in the fire box itself. Probably the most successful arrangement is that devised by Mr. Drummond for the London and South-Western Railway Company. It consists of short water tubes placed across the fire box between the water spaces at the sides, with a slight inclination to improve the circulation. Although the system has not been adopted by the other companies, it has been well reported of by the London and South-Western Railway Company. Continental locomotives are sometimes provided with long water tubes arranged to carry the brick baffle plates, but such devices are not favoured by British engineers. Brass and iron are the materials most generally used in this country for smoke tubes, whereas in America steel is very frequently adopted, especially when mild steel is the material used throughout the boiler. To facilitate the insertion of the tubes through the smoke box, the end of the tube at the fire box is reduced in diameter, while the smoke-box end is increased. When the tubes are of copper they are expanded into the holes in the fire-box tube plate and beaded over, but at the smoke-box end they are merely

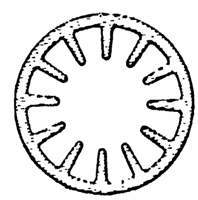


Fig. 190.—Section of Serve Tube

expanded without beading over, in order to prevent excessive stresses through relative expansion of the parts, and about ½ in. of the length is left protruding through the plate. When steel or iron tubes are used it is more difficult to make the junctions at the tube plates secure, unless the tubes are fitted with soft copper sleeves where they are expanded into the plates.

SUPERHEATERS

Within recent years the use of superheated steam has become more general, although, as in the case of the compound locomotive, the system is by no means universally approved in this country. In general, the principle of the superheater consists in passing the steam through tubes arranged in the course of the gases, generally at the smoke-box end. To accommodate the superheater, the smoke box is in many cases extended into the boiler barrel by placing the tube plate farther back. Another arrangement consists, as in the Schmidt superheater, in making the upper smoke tubes of large diameter, and in placing within them tubes through which the steam is circulated. On the Prussian State railways certain of the locomotives are fitted with the Pielock superheater, which is arranged over a section of the fire tubes themselves near the smoke-box end. The steam is passed into the casing, and is caused to circulate, by means of baffle plates, up and down across the smoke tubes before passing to the cylinders.

No definite relationship between the grate area and the total heating surface can be specified, as this varies with the working conditions that are to be satisfied. In the case of high-grade express engines the ratio of grate area to total heating surface may vary as 1 to 75 or 1 to 65. One of the largest express engines of the Great Western Railway Company has, for example, a ratio of 1 to 75 with a grate area of 20.8 sq. ft., and a total heating surface of 1560 sq. ft., consisting of 1433 sq. ft. of tube area and 127 sq. ft. of fire-box area. These dimensions are greatly exceeded in many of the large American freight engines, which are provided with grate areas of as much as 58 sq. ft. and total heating surfaces of 5000 sq. ft.

SMOKE BOX

To a very considerable extent the steaming power of the locomotive boiler depends upon the careful design and arrangement of the smoke box. Apart from its primary use as a smoke chamber from which the gases from the fire tubes pass away through the chimney, the smoke box serves several indirect purposes. It arrests sparks, and by providing space for the accumulation of cinders prevents their discharge through the chimney into the air. It accommodates the blast pipe, and protects the steam piping, and to some extent the cylinders, from the cold air. It also gives ready access to the fire tubes for cleaning purposes. The front of the box is closed by an air-tight door, through which the accumulations of ashes may be removed and the tubes cleaned. Air-tightness at this point is essential, as a badly fitting door will seriously reduce the draught and consequently the steaming power of the boiler.

Artificial means of inducing the draught must be resorted to, as it is quite impossible in the locomotive to obtain a sufficient height of chimney for the purpose of natural draught. The exhaust steam is accordingly allowed to escape through the restricted opening of the blast pipe, and thus by reducing the pressure in the smoke box to induce the necessary draught through the tubes. An orifice of small diameter produces a sharp fierce draught but increases the back pressure of the exhaust steam in the cylinders. A large orifice, on the other hand, while reducing the back pressure, may not give the required draught. It is therefore necessary to make a compromise between the requirements, or to fit some arrangement whereby the orifice area may be varied to suit the running conditions. Devices of this description are not favoured by British engineers owing to the complication of the gear that is generally involved. Importance also attaches to the position of the blast-pipe orifice relatively to the tubes, as uniformity of the draught through all of them is difficult to obtain even with the use of baffle arrangements. It is only within recent years that the size of the smoke box has been increased to dimensions more in accordance with those of foreign locomotives. The box is extended either towards the front or in towards the barrel, the former arrangement being the one more generally adopted. With the extended box there is more space for the accumulation of ashes, which otherwise tend to obstruct the draught, and, owing to the greater regularity of the vacuum, the steaming power of the boiler is improved.

CYLINDER ARRANGEMENTS

Simple locomotives are provided with two, three, or four cylinders, although the great majority have only two. Articulated locomotives being practically double-ended engines are not here considered.

Some reference has already been made to the arrangement of the cylinders either between or on the outsides of the frames. In the former case the pistons drive a cranked axle, while with outside cylinders the wheels themselves are directly driven and the main axle is continuous. Owing to the restricted width between the frames the space available for two cranks and two sets of eccentrics is very limited, and when the boiler is of large diameter or low pitched, there is the added difficulty of obtaining sufficient headroom for valve gears of the link type. These objections, and the superiority of the continuous axle over the cranked driving axle, make the adoption of outside cylinders in many cases desirable, notwithstanding the appreciable losses resulting from the exposure of the cylinders to the air. Three-cylinder simple engines have been used on certain railways for extra heavy traffic, but unless the total cylinder volume is not thereby increased, the boiler must be correspondingly enlarged to derive any advantage from the third cylinder. It should be noted that by reducing the cylinder diameter the forces are proportionately reduced, and the parts may be made lighter; but the increase in the number of the cylinders involves additional gear and complication that may more than counterbalance the advantages. Several three-cylinder simple engines are used on the Berlin Metropolitan Railway for the heaviest sections of the traffic. Two of

the cylinders are placed outside the frames and drive one pair of wheels directly, while the third lies between the frames and works the crank of the second driving axle.

Four-cylinder engines offer certain advantages as regards steady running, in addition to those advantages already referred to in the case of three cylinders. It is easier to balance the horizontal reciprocating motions of four pistons, and thus to reduce the alternate sideways straining of the frame. Two of the cylinders are arranged between the frames and two outside, each pair driving a different axle, but this necessitates two extra sets of valve gears. By placing the cylinders all in one line, side by side, so as to drive one axle, the four valves can be operated in pairs by two gears, but the advantage of distributing the driving forces over two axles is thereby lost.

COMPOUND LOCOMOTIVES

Continental engineers have for many years made extensive use of the compound locomotive, but it is only recently that the practice has advanced in Britain, and at the present time the merits of the system are seriously discounted by many, especially when expansion in stages is advocated for all kinds of fast or slow traffic. Marine engineers derive the greatest advantage from compound working when the speed is not great and when the power developed is uniform. This agrees with the experience of locomotive engineers, who have obtained the best results from compound locomotives when hauling heavy loads over long distances at comparatively slow speeds. These conditions are more frequently met with in America and on the Continent than in Britain, and this may account for the very different opinions that have been formed regarding the value to be derived from the compounding of locomotives, although the unfavourable opinion held by British engineers may be the result, to some extent, of prejudice. In Britain the system has been most extensively adopted by the London and North-Western Railway Company, who have in daily service a large number of express passenger engines designed by Mr. Webb. The general experience with compound engines, as at present built, appears to be that in the majority of cases the gain is not sufficiently definite to warrant the added complication, increased cost, and upkeep; although in some cases the conditions are such as to make the working of the system economical.

It is not possible to describe in detail all the arrangements of cylinders adopted by the different designers of compound engines. Two-cylinder compounds have been almost entirely discarded, owing principally to the one-sided arrangement of two cylinders of different diameters. With three cylinders a more symmetrical arrangement is possible, the high-pressure cylinders being carried on the outsides and the low-pressure cylinder between the frames. Many three-cylinder compounds were designed by Mr. Webb for the London and North-Western Railway Company, but the engines now built by them are without exception fitted with four cylinders arranged side by side under the smoke box, and all driving one axle. Figs. 156 and 157 illustrate a three-cylinder arrangement in which the low-pressure cylinder between the frames drives the first cranked axle, while the high-pressure cylinders carried on the side frames are placed sufficiently far back to drive the crank pins of the second pair of coupled driving wheels. Three

motions of a radial type are provided for working the valves, which are arranged on the under sides of the high-pressure cylinders and on the upper side of the low-pressure cylinder. The Glehn four-cylinder system is somewhat similar to the above, but instead of one low-pressure cylinder there are two placed between the frames. When the cylinders are arranged in one line, side by side, it is possible to combine two of the motions so that the four valves may be controlled by one pair of gears, thus effecting a considerable saving in the number of moving parts and in the cost of running. Experience has proved the value of providing means whereby the point of cut-off in the low-pressure cylinders may be varied independently of the cut-off in the high-pressure cylinders. In certain cases of compound engines not so fitted, the results obtained have not been satisfactory until the gears have been altered to give independent control of the cut-offs.

A compound locomotive is primarily intended to economize coal, but the indirect advantages are of considerable importance. Since the steam is more efficiently consumed, the demands upon the boiler are not so serious as is the case in the heavy-grade single-expansion engines. An increase of efficiency does not, however, necessarily mean an increase of the power of the engine as a whole, and it is surplus power that is most wanted on the heavier parts of the route. Arrangements are accordingly made for admitting live steam to the low-pressure cylinders when starting or on heavy gradients. The admission may be effected automatically when the lever is placed in the forward starting position, or by hand, as required. The intercepting valve provided for the purpose closes the passage between the high-pressure and the low pressure cylinders, opens a communication from the high-pressure exhaust to the chimney, and admits live steam to both high- and low-pressure cylinders. In the A. von Borries' automatic intercepting-valve system, the act of placing the starting lever in the forward position admits steam at a slightly reduced pressure through a small aperture into the intercepting valve chamber, and by closing the valve prevents the passage of the steam back into the receiver between the cylinders. The exhaust from the high-pressure cylinder is meanwhile entrapped in the receiver behind the valve, and after a few strokes the pressure rises sufficiently to again open the intercepting valve, and at the same time to cut off the supply of live steam to the large cylinder. The high-pressure exhaust then passes from the receiver to the low-pressure cylinder, and the engine continues to work on the compound principle.

VALVES AND VALVE GEARS

For ordinary single-expansion locomotives using steam at pressures up to 180 lb., ordinary **D**-slide valves are generally used in preference to the piston valves that would probably be used for land or marine engines. The working conditions are very dissimilar, and this accounts for the differences in practice. In the locomotive there is greater difficulty in supplying dry steam to the cylinders, and under such conditions any accumulation of water finds a readier escape at the face of a flat valve. When running down gradients with steam cut off a vacuum is formed in the cylinders, and unless special

arrangements are provided for the admission of air the gases and grit of the fire box are sucked in through the valves. Piston springs and valve faces are thus subjected to an amount of wear that makes the use of complicated parts undesirable. Some arrangement of balanced valve is frequently adopted when the area of the valve is considerable and the pressure is high, in order to reduce the power required to overcome the frictional resistances at the working faces. The commonest arrangement comprises a framework which prevents the steam pressure from acting upon the back of the valve, but as packing springs are involved the arrangement is open to the objections already stated. In the case of compound locomotives the conditions are somewhat different, and considering the high pressures adopted it is very customary to fit piston valves to the high-pressure and D-valves to the low-pressure cylinders.

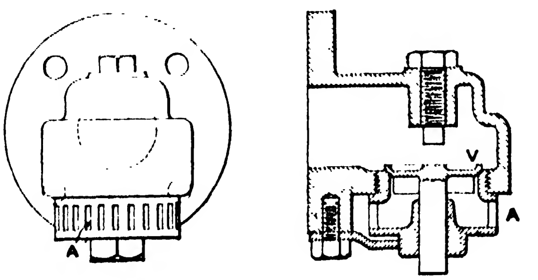


Fig. 191

Fig. 191 shows a typical valve for destroying the vacuum in the cylinders when running with steam cut off. When the pressure in the cylinder falls below that of the atmosphere, the valve V rises, and the air which enters through the apertures A passes into the valve chest and cylinders, and is then exhausted into the fire box. In this way the entrance of grit is effectually prevented. Without the use of such a valve the trouble

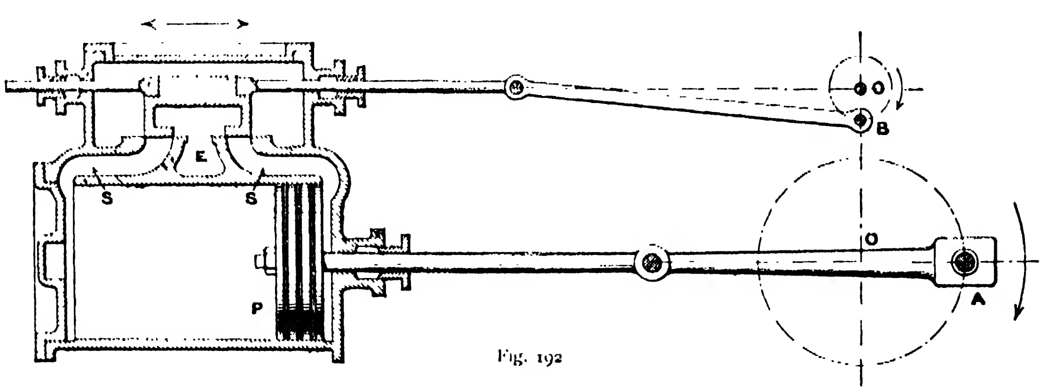


Fig. 192

may be to some extent overcome by placing the slide valve in the full working position immediately after the steam has been cut off.

A special relief valve is also fitted to the steam chest, with connections to the various parts, to be protected against the accumulation of water when the distribution valve is of the piston type.

The position of the steam valves depends upon the design of the locomotive as a whole; thus, for example, when the cylinders lie between the frames and do not exceed 18 in. in diameter, it is possible to place the valve chest between, but when the diameters exceed 18 in. the space is very limited, and the valves must be otherwise arranged, either horizontally underneath or above the cylinders. In the former arrangement better draining of the casings is possible, while in the latter the steam supply is more direct and the losses from cooling are less.

Valve Gears.—Distribution of the steam to and from the cylinders is effected by the valve motion, but the gear serves the additional purposes of varying the steam expansion and reversing the action as required.

For the sake of simplicity of description, only the essential parts are shown in the diagrams, figs. 192 and 193. O A is the crank driven by the piston, and O B is the crank equivalent to the eccentric which moves the slide valve to and fro over the steam

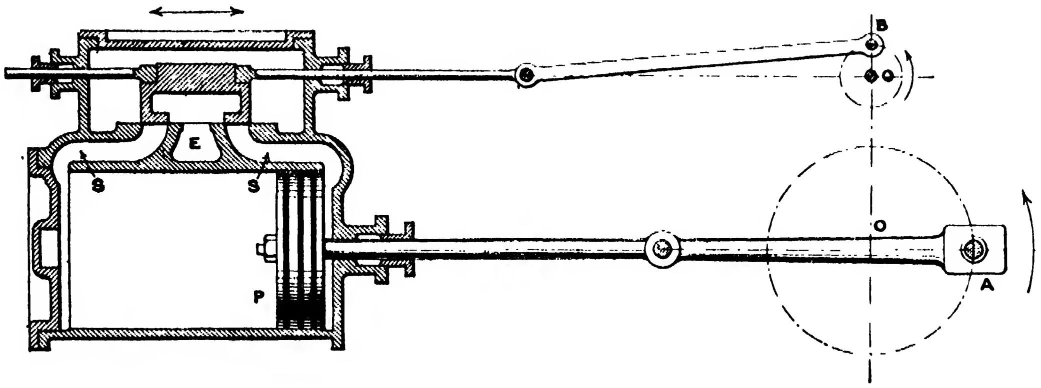


Fig. 193

and exhaust ports S and E. The two cranks O A and O B are shown separated, but in reality the axle O is common to both. In the figures the piston is shown in the outer dead-centre position, with the valve in mid travel and cutting off the steam supply. The valve cranks, on the other hand, are shown occupying positions 90 degrees in advance of the main crank in fig. 192, and behind it and fig. 193. Under these conditions it will be evident that continuous motion can only take place in the directions of the arrows. Any rotation in the opposite direction would only open the same working side of the piston once more to the steam supply and bring the piston back to the end of the stroke. It follows, therefore, that the rotation must always be such that the eccentric leads the driving crank. To reverse the engine, means must be provided for reversing the position of the eccentric relatively to the crank, that is, the gear must permit of the eccentric being placed always in advance of the crank, to suit the required direction of rotation. Locomotives in the days of the industry were fitted with the "Gab" arrangement shown in fig. 194. Two eccentrics, set in opposite directions relatively to the crank, were keyed to the shaft, and the ends of their connecting rods provided with hooks which could be made to engage by hand with a stud on the slide-valve rod. To reverse the engine, all that was required was to disengage the one eccentric rod, and at the proper moment engage the other. Another and still simpler arrangement

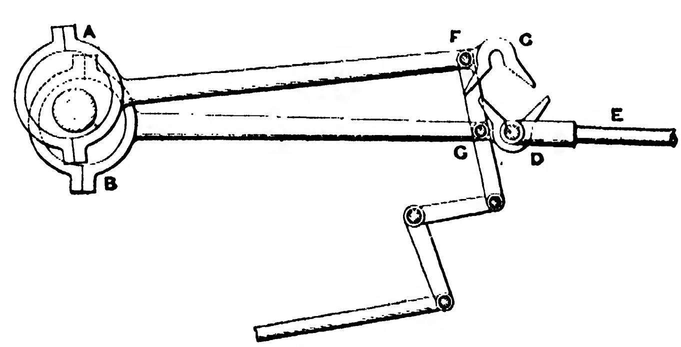


Fig. 194.—"Gab" Valve Gear

involved the use of only one eccentric, which was loose on the shaft and driven by it through a stop piece. To reverse the rotation the eccentric-rod hook was lifted out of gear with the stud, and the valve manœuvred by hand until the correct relative positions of the eccentric and crank were obtained, when the hook once more was made to engage the valve stud. A gear of this description makes reversal of the engine possible, but it does not permit of the cut-off being varied at will, and the steam distribution is not satisfactory. Other gears were accordingly devised to overcome these objections, the most satisfactory and universally used arrangement being the Stephenson link motion; but before describing this gear, the explanations of the terms lead and lap, already described in the chapter on the steam engine, must be repeated here. If the valve were of the simple form illustrated in fig. 192, the steam would be admitted to the cylinder or exhausted throughout the travel of the piston, and under these conditions there would be considerable knocking in the bushes at each reversal of the motion, and therefore of the stresses. To overcome the difficulty, steam is admitted to the exhaust side before the piston has reached the end of its stroke, and this is done by increasing the angle between the eccentric and the crank, thus advancing the action of the slide valve relatively to the piston, and the valve is then said to have lead. Apart from this question of lead, it will be seen by again referring to the diagram, fig. 192, that a full cylinder of live steam would be consumed at each stroke, if the breadth of the valve faces were just sufficient to cover the ports. To make expansive working possible, the valve faces are made to overlap the ports on the outer edges. The valve is then said to have outside lap, which cuts off the steam supply at an earlier stage in the stroke, depending upon the amount of the lap. From the point of cut-off, the piston is driven solely by the expansion of the steam. In stationary engines, as already explained, and to a slighter extent in the locomotive, some lap is also given to the inside exhaust edges of the valve, to assist in the reversal of the direction of motion at the ends of the strokes by providing more cushioning action. With the valve gear it must also be possible to vary the degree of expansion, that is, the point of cut-off from a certain fixed point to zero, and this is best effected by varying the travel of the valve. Referring to the simple valve, fig. 192, it will be evident that with the full travel of the valve, steam will be admitted throughout the stroke of the piston, but that with a shorter travel of the valve the ports will be open for a shorter period, and a correspondingly smaller quantity of steam will be admitted. When the travel is reduced to nothing the ports will remain closed, no steam will be able to enter the cylinder, and the engine will stop. Some mechanical equivalent to an eccentric of variable throw is required to give the necessary control of the valve travel, and this is the principle underlying the great majority of the motions commonly used. In the Stephenson link motion, fig. 195, the effects of two oppositely set eccentrics are combined by means of a slotted link which engages with the valve rod. When the middle of the link engages the rod, the opposite movements of the eccentrics neutralize one another at that point, and the travel of the valve is zero. No steam can under these conditions enter the valve, although the supply is not cut off from the valve chest. When one end of the slot engages the valve rod, the effect of the eccentric coupled to that end is a maximum, and the effect of the other eccentric zero. The valve has then the

maximum travel, and the engine will move forwards or backwards according to whichever of the eccentrics is in full gear. For any intermediate point of the link the valve travel will be the resultant of the opposed eccentric motions. Stephenson's motion in practically its original link form is used by many present-day engineers for all types of locomotives. Other gears have been devised to overcome certain objections, and to suit conditions imposed in the design of the locomotive, but none of these excels the above simple arrangement in all particulars. What is generally known as the

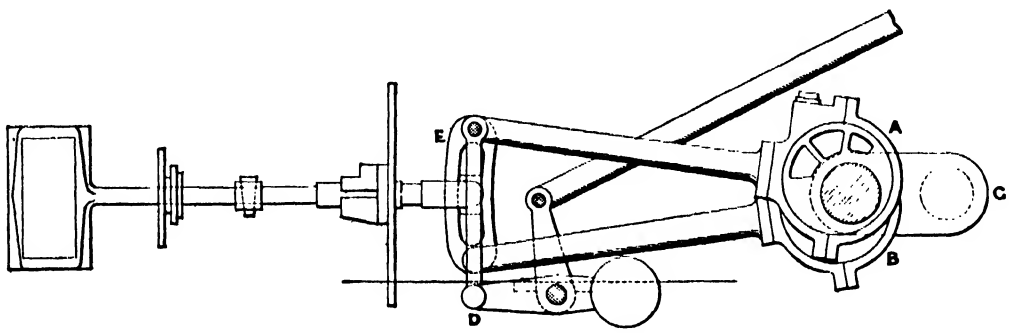


Fig. 195.—Howe or Stephenson Link Motion

Stephenson link motion is in reality the arrangement devised by Howe and introduced by Stephenson. The original Stephenson gear consisted of an arrangement of forks which engaged the valve rod. Since each eccentric of the link gear has a definite fixed lead, it will be evident that the valve lead cannot be constant for intermediate linked positions where the motion is the resultant of the combined eccentric movements, and that the amounts of the release and compression will be affected in the same way. Improved gears have been devised with the main intention of overcoming these objections, but no one of them can be said to excel the simple link motion in every respect.

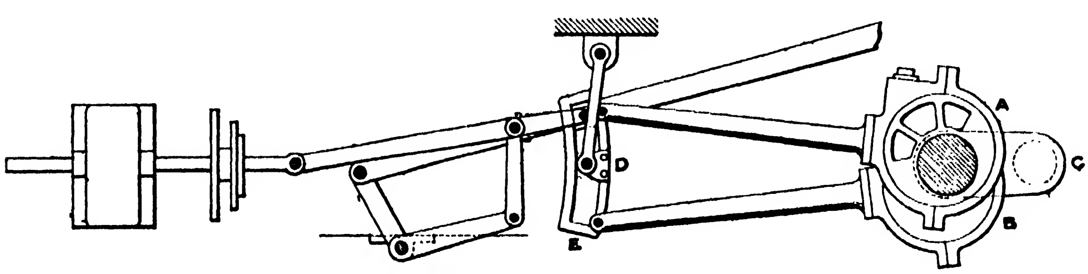


Fig. 196. Gooch Link Motion

What is gained in more efficient distribution of the steam at points of early cut-off is too often lost in increased complication. In the Gooch link motion, fig. 196, the centre of the slot-link curve is at the eccentric-rod pin, while in the Stephenson motion the link curve is centred about the eccentric sheave. The Gooch link is suspended from a fixed point, and it is the slide block, not the link, that is raised and lowered by the hand gear. When the valve is in the middle of its travel the rod end can be raised or lowered in the slotted link without producing any movement of the valve, that is to say, the lead is constant for all positions of the gear. By moving both the link

and the rod slide, Allan succeeded in substituting a straight link for the curved ones previously used, but the lead is not entirely constant as in the Gooch gear.

It is not always possible, especially in the more powerful locomotives, to find sufficient room between the frames for the double-eccentric link motions, while the large diameters of the cylinders necessitate some other arrangement of the valves either above or below them. Radial gears have accordingly been devised to work such horizontally placed valves, and at the same time to dispense with the use of the eccentrics. The valve motion is in general compounded of a reciprocating motion synchronizing with that of the piston, and of a rotary motion derived from that of the crank.

Hackworth's gear, the earliest of the radial valve motions, makes use of only one eccentric, and is for this reason frequently used for locomotive engines. The valve rod is worked from a point in the eccentric rod the position of which must be chosen

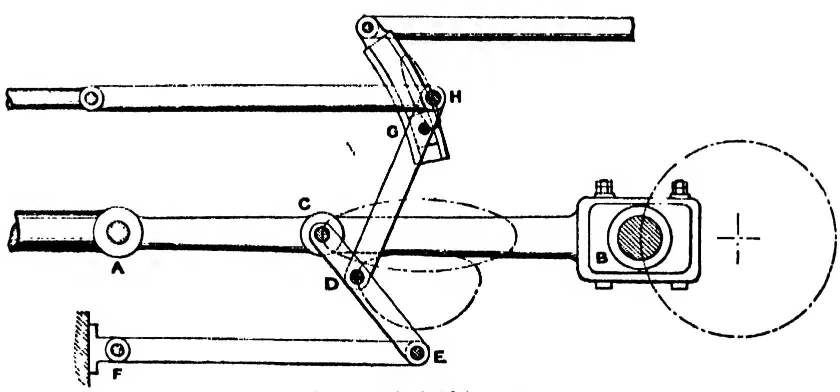


Fig. 197.—Joy's Valve Gear

to give the required leads. To reverse the engine the end of the rod is made to work in a slot the inclination of which may be altered by the hand-reversing lever.

In Marshall's gear, which is a modification of the Hackworth arrangement, the end of the eccentric rod, instead of working in an adjustable guide, swings on a radius rod carried upon an arm of the reversing quadrant. There are many other arrangements and modifications of the Hackworth gear, but it is not possible here to enumerate them.

Joy's valve gear (fig. 197) is specially suitable for the locomotive, as it consists of very few and simple parts, and at the same time gives a satisfactory distribution of the steam. Since the end A of the piston rod moves in a straight line and the crank B in a circular path, an intermediate point such as C of the connecting rod will trace an ellipse. A point D on the link C E, which is coupled to the connecting rod at C, and at E to the radius bar E F, will have a motion compounded of the ellipse traced by C and the circular path of the end E. The lever which operates the valve rod is carried by a slide working in a slotted guide, the pivot being close to the valve-rod end. By a suitable choice of the pivot points, the horizontal motion of the end H can be so adjusted that the reduced motion of the valve rod will be twice the lap and lead. At the same time the vertical movement of the end D causes the slide to rise and fall in the guide, which according to its inclination determines the valve travel, and therefore the point

of cut-off. The guide is pivoted on a bracket upon the engine frame, and its inclination can be altered as required by means of the reversing lever.

On the Continent the Walschaert gear, illustrated in fig. 198, is almost universally employed for locomotives, but it is only within comparatively recent years that British engineers have to any extent adopted it. Although considerably more working parts are involved, the gear occupies very little side room and does not necessitate the use of any eccentric. It is therefore especially suited to locomotives with outside cylinders, or where there is no room between them and the frame for the motion. Outwardly the gear has an appearance of much complication, and it is doubtless this that has so long prevented its adoption by British engineers. Continental engineers, on the other hand, have long favoured it, and at the present moment it is applied to the great majority of their engines. In Germany the gear is known as the Heusinger or Waldegg gear, from the name of an independent German inventor, Edmund H. Heusinger von Waldegg. Walschaert's patent, however, anticipates that of Heusinger by five years, the Walschaert

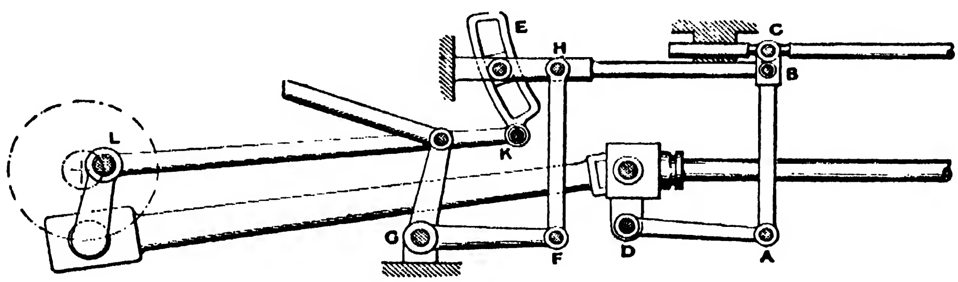


Fig. 198.—Walschaert Valve Gear

patent being dated 5th October, 1844. For certain reasons the patent was actually filed in the name of a Brussels engineer, F. Fischer.

Fig. 198 illustrates an arrangement commonly used at the present day. It consists of a "combining lever" A B C attached by a link at A to a point D fixed to the piston crosshead. The motion of A is thus synchronous with that of the piston. The short arm of the combining lever receives its motion from a link pivoted at its middle, and oscillated by a small throw return crank on the driving axle. At the point C is connected the valve rod, which thus receives a motion compounded of those derived from the piston crosshead and the crank. Considering first the piston component, the travel of the valve is determined by the ratio C B to B A of the lever arms, and these are so chosen as to give the required lap and lead, which are therefore constant for all degrees of expansion. The short end of the combining lever is worked by a radius bar from the link E, and the valve motion thus derived from the crank depends upon the position of the slide in the link. When the slide occupies the lowest link position, the engine moves say forward, and in the reverse direction when the slide is at the opposite end. Intermediate positions give corresponding degrees of expansion. The adjustable radius bar and slotted link thus serve the purpose, as in the Gooch link (fig. 196), of reversing the engine and of determining the point of cut-off, while the small crank, on account of its being set at right angles to the driving crank, not only gives the valve its motion,

but also moves it most quickly at the positions of cut-off and release. Many variations of the Walschaert gear have been introduced, but the principles of all of them are already sufficiently well described.

LOCOMOTIVE PROPORTIONS

The minor details and fittings of a locomotive to which it has not been possible to refer are clearly indicated on the cardboard model, and by means of the illustrations of the two typical modern locomotives included here.

The first illustrates a six-coupled side-tank locomotive, built by Messrs. Barclay, Sons, & Co. of Kilmarnock; and the second an articulated compound locomotive built by Messrs. Borsig of Berlin for the Central Northern Railway of the Argentine Republic.

SIX-COUPLED SIDE-TANK LOCOMOTIVE

Built by Messrs. Barclay, Sons, & Co., Ltd.

(Figs. 199 and 200)

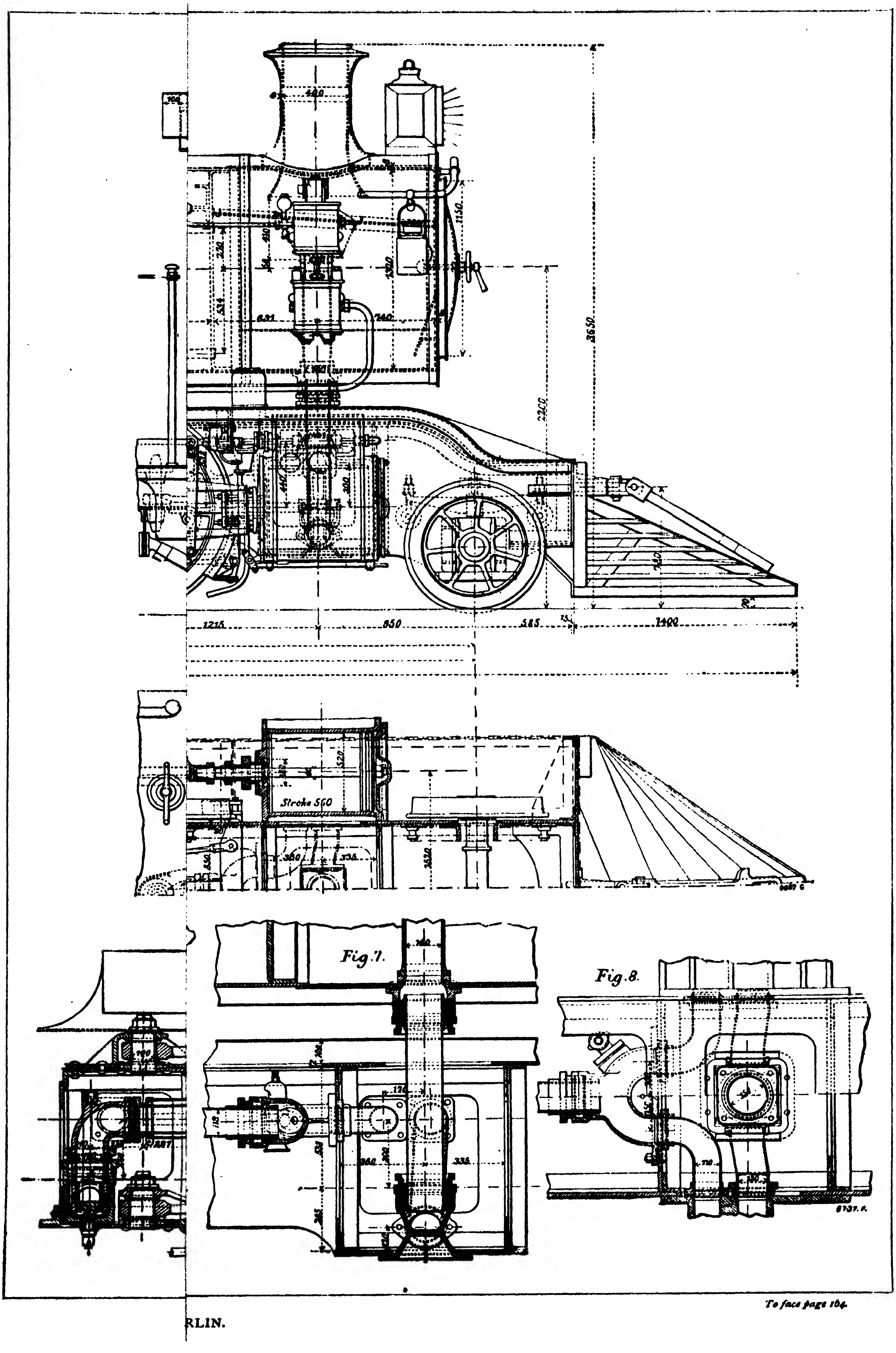
Leading Particulars:

Gauge	4 ft. $8\frac{1}{2}$ in.
Cylinder diameters	17 in.
Piston strokes	24 ,,
Wheel diameters	4 ft.
Wheel base	$14\frac{1}{2}$ ft.
Heating surface	
Tubes	870 sq. ft.
Fire box	95 ,,
Total	965 ,,
Grate area	15 ,,
Tank capacity	900 gallons.
Coal capacity	1 ton, 13 cwt.
Weight in running order	44 tons, 10 cwt.

The cylinders are between the frames, and particular attention has been paid to the bracing together of the side frames, which are also made specially heavy to withstand the severe stresses that are met with in such work as shunting.

Compensating beams are provided between the leading and the driving springs on each side, while the trailing axle is carried by a single spring arranged transversely.

Hand and steam brakes acting upon all the wheels are provided. The fire box is of the Crampton type, but has the wrapper plate raised above instead of being continuous with the top of the barrel.



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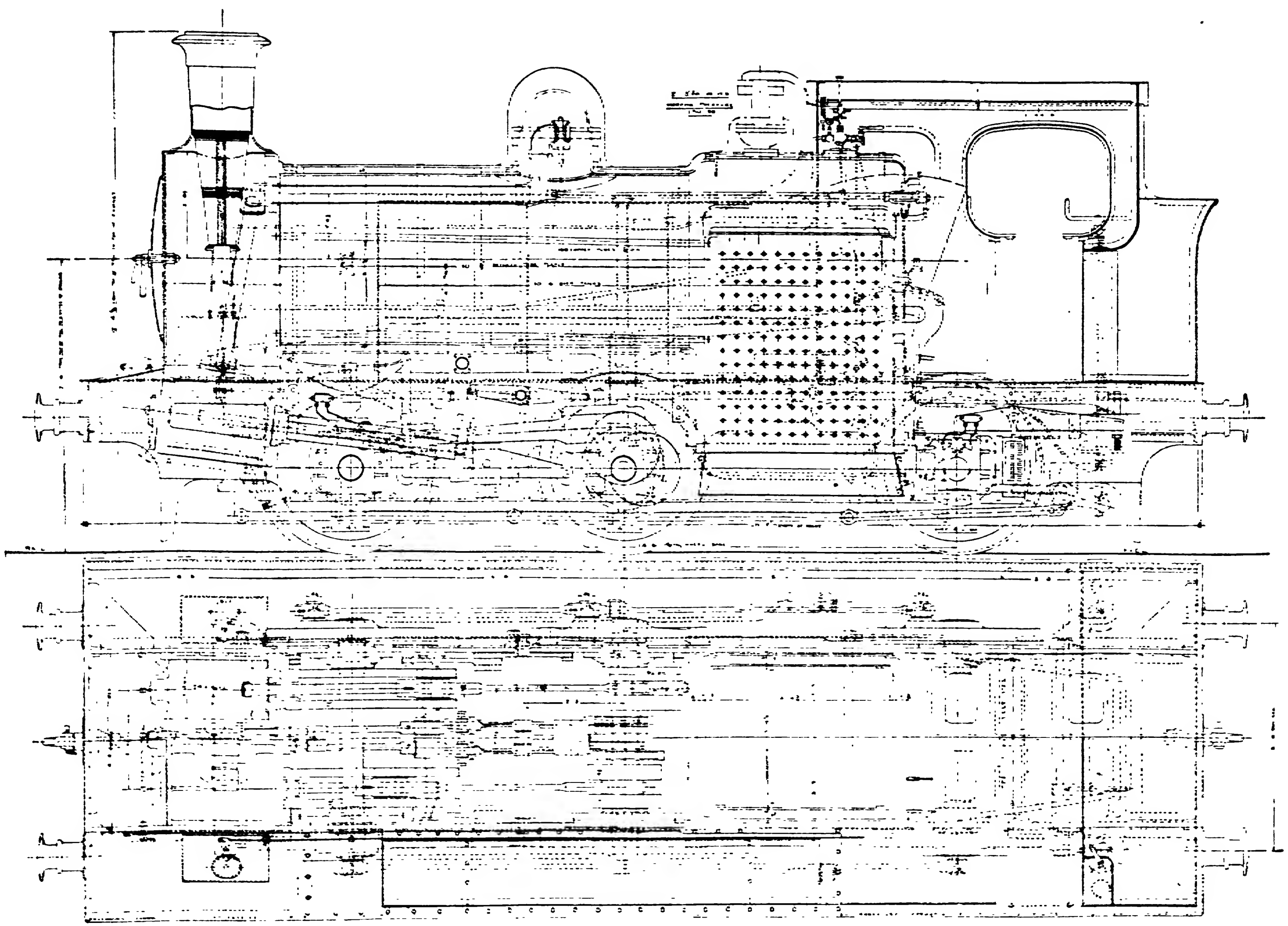

Fig. 199

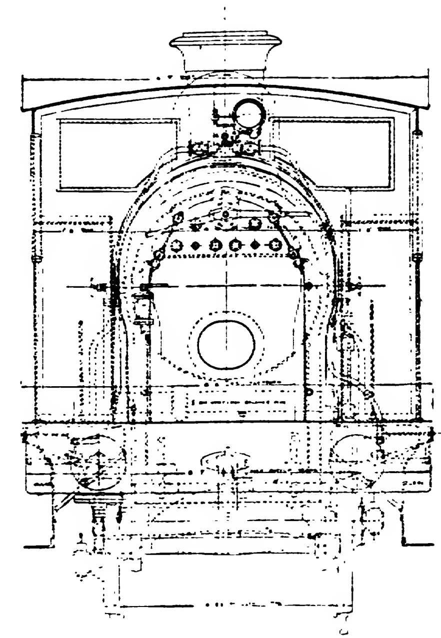

Fig. 200.—Arrangement of Six-Wheel Coupled Side-Tank Locomotive (Inside Cylinders)

Cylinders, 17" diameter × 24" Stroke, Gauge, 4' 8½".

(And. Barclay, Sons, & Co., Ltd., Kilmarnock.)

COMPOUND ARTICULATED PASSENGER LOCOMOTIVE

By Messrs. Borsig of Berlin

(See Plate, figs. 1–8)

Fig. 1 is a complete side view.
Fig. 2 is a half-sectional plan showing the disposition of the cylinders.
Figs. 3, 4, 5, 6, 7, and 8 show in detail the flexible arrangement of the steam-pipe connections.

Leading Particulars:

Gauge	3 ft. $3\frac{3}{8}$ in. (1 metre)
Diameter of high-pressure cylinder	13 in.
Diameter of low-pressure cylinder	$20\frac{1}{2}$ in.
Stroke of pistons	$21\frac{5}{8}$ „
Diameter of coupled wheels	4 ft. $3\frac{1}{4}$ in.
Diameter of bogie wheels	2 „ $7\frac{1}{2}$ „
Rigid wheel base	10 ft.
Total wheel base	29 ft. 4 in.
Height of boiler centre	7 ft. $2\frac{3}{4}$ in.
Mean diameter of barrel	4 „ 4 „
Number of brass tubes...	207
External diameter of tubes	2 in.
Length of grate...	8 ft. $6\frac{1}{2}$ in.
Width of grate	4 „ $0\frac{7}{8}$ „
Grate area	35 sq. ft.
Heating surface...	1820 sq. ft.
Working pressure	170 lbs.
Weight empty	41 tons, 2 cwt.
Weight in running order	47 tons.

The fire box is of the Belpaire type and built of copper. It has the two front rows of roof stays articulated to permit of vertical expansion of the tube plate.

The high pressure cylinders are fixed to the rear frames in order to obviate the necessity of any flexible steam joints under the full boiler pressure. Walschaert gear is used throughout, and provision is made for independently varying the cut-off in each pair of cylinders.

LOCOMOTIVE

Index to the Principal Parts

1. Boiler Cover
2. Cab Roof.
3. Steam Dome
4. Safety Valve.
5. Funnel.
6. Driving Wheels.
7. Trailing Wheels.
8. Steam Cylinder.
9. Regulator Rod.
10. Expansion-link Lever.
11. Link Connecting Rod.
12. Controlling Hand Wheel.
13. Sand Box.
14. Sand Pipe.
15. Sand Blast.
16. Step.
17. Coupling Rod.
18. Connecting Rod.
19. Crosshead.
20. Guide Bars.
21. Guide-bar Bracket
22. Crank.
23. Balance Weight.
24. Crank-Pin.
25. Axle.
26. Piston Rod.
27. Piston.
28. Eccentric.
29. Expansion Link.
30. Expansion-lever Spindle.
31. Bracket for 30.
32. Link Suspension.
33. Slide-valve Rod.
34. Slide Valve.
35. Valve Chest.
36. Steam Admission.
37. Steam Exhaust.
38. Blast Pipe.
39. Steam Pipe.
40. Cylinder Cover.
41. Bogie Pivot.
42. Pivot Pin.
43. Bogie Axles.
44. Bogie Wheels.
45. Carrying Springs.
46. Spring Suspension Links.
47. Spring Bearers.
48. Buffer.
49. Draw-bar Hook.
50. Coupling Links.
51. Cowcatcher.
52. Signal Lamp.
53. Smoke Box.
54. Smoke-box Door.
55. Bolt for 54.
56. Steam Pipe.
57. Steam Regulator.
58. Regulator Shaft.
59. Regulator Lever.
60. Boiler.
61. Boiler Tie.
62. Fire Box.
63. Crown Tie Bars.
64. Fire Bridge.
65. Fire-door Arch.
66. Fire Door.
67. Fire Bars.
68. Supports for 67.
69. Ash Pan.
70. Coal Box.
71. Lever for 72.
72. Drain Cocks.
73. Smoke Tubes.
74. Side Frames
75. Horn Blocks.
76. Rod for 72.
77. Crank Lever for 72.
78. Brake-block Suspension.
79. Brake Block
80. Brake-block Rods.
81. Brake-rod Crank.
82. Brake Cylinder.
83. Draw Bar.
84. Flexible Pipe.
85. Lubricators.
86. Steam Whistle.
87. Pressure Gauge.
88. Injector.
89. Signal-cord Lever.
90. Draw-bar Pin.
91. Blow-off Cock.
92. Wheel Covers.

(*Model prepared from drawings kindly supplied by* The North British Locomotive Co., Limited, Glasgow.)

Section IV

CONTINUOUS RAILWAY BRAKES

CONTINUOUS RAILWAY BRAKES

Whenever it is necessary to bring a moving train to rest, the energy stored in the moving mass must in some way be dissipated, and in practice the dissipation of the energy must be effected with considerable rapidity. This may most readily be done by converting the energy of motion into heat, either by blocking the wheels wholly or partially. In the former case the heat results from the friction between the locked wheels and the rails, while in the latter case some of the energy is dissipated in friction between the brake blocks and the wheels. The blocks, in the simplest arrangement, are pressed against the wheel tyres by a screw gear or by a combination of levers which multiplies the force exerted by the brakesman before its application at the tyres. A certain number of vehicles fitted with such brakes were placed in different parts of the train in the earlier days of railway working, and at a given signal the brakes were applied simultaneously, or as nearly so as possible, whenever it was desired to stop the train. For light local goods traffic, where the speed is very moderate, this system is still in use, but never in the case of passenger or heavy goods trains. It will be readily understood that such a system is much too dangerous for application to express trains, which may be called upon by the signals at any moment to stop suddenly. As the rapid improvement of the locomotive made it possible to haul trains of greater and greater weight, it was found necessary to group the brakes together upon one or more of the vehicles.

DEVELOPMENT OF THE CONTINUOUS BRAKE

Loughridge's chain brake, which dates from about 1865, was of this class. It consisted of an arrangement of pulleys and chains running the whole length of the train and connecting all the brakes. One mechanic was thus able to operate them all, by means of a hand lever placed near him. Arrangements of this kind, which enable all the brakes from one extremity of the train to the other to be worked simultaneously and from one position, are called "continuous brakes".

None of the continuous mechanical arrangements devised for applying the brakes could be considered as a practical solution of the problem. It was only by the invention of the continuous pneumatic brake that all the requirements were met in a truly practical manner. In the pneumatic system, a tube carrying air, either compressed or below atmospheric pressure, is led along the whole length of the train. A connection is made to each vehicle brake cylinder, and flexible couplings are used between the vehicles to make the air passage continuous. The history of this ingenious appliance is of sufficient interest to warrant a brief summary.

About the year 1833 Stephenson invented the steam brake, which consisted simply of a steam cylinder the piston of which acted directly upon the levers operating the brake shoes.

The first brake which really merited the name of pneumatic was one invented by James Nasmyth and Charles May in 1844.

In 1848 Samuel C. Lister patented an air brake which comprised a compressing pump, a main reservoir, and an air tube connected between the carriages by means of couplings. This arrangement embodied the essentials of a really continuous brake, and resembled the brakes in use at the present day in all particulars, with the one exception that it was controlled by the guard, and not by the mechanic on the locomotive. Since then, innumerable patents have been taken out in every important country for all kinds of continuous brakes. During the last seventy years of the nineteenth century over 650 such patents were applied for in Britain, 21 being for railway brakes operated by electro-magnetic means, 20 for hydraulic, 32 for pneumatic, and 50 for steam brakes. In America, during this time, over 305 patents were filed for railway brakes of all descriptions. Notwithstanding the great attention devoted about this time to the subject, it was not until certain improvements by George Westinghouse were carried out that any rapid progress was made. In 1869 he devised his non-automatic air brake, to which he gave the generic name of "the direct air brake". It consisted of an air compressor worked by steam and placed upon the locomotive, and of a reservoir in which the compressed air was stored. An air pipe was run along the train and connected between the carriages by means of couplings. Under each vehicle was placed a cylinder communicating with the air-supply pipe, and fitted with a piston connected to the brake-shoe levers. Each time air was admitted to the air pipe, the pistons of the cylinders were forced out and the brakes applied. When, on the other hand, the supply was cut off and the air pipe put into communication with the atmosphere, the compressed air escaped and the brakes released themselves. One simple three-way cock, between the train pipe and the reservoir of compressed air, served to admit the air to the pipe communicating with the brake cylinders, or to open it to the atmosphere, or to completely isolate it. In 1872 Westinghouse applied his system in America for the first time. This date may indeed be considered as the starting point of the later great development in the transport of goods and passengers over railway lines.

In the same year (1872) a vacuum brake invented by Smith was introduced in England, at first as a direct brake, but later in an automatic form.

Westinghouse's brake was first introduced into France in 1877 by the Compagnie de l'Ouest, and Smith's brake a year later, in 1878, by the Compagnie du Nord. After

various experiments, inevitable to the introduction of any new idea, the apparatus was rapidly brought to a state of such perfection that it was found possible, in 1880, to make the use of such brakes compulsory upon all vehicles forming part of any passenger train. From this period onwards progress was very rapid. Long heavy trains, it was found, could be stopped in a very short space of time; and as confidence in the certainty of action of the pneumatic brake grew, the speeds and the weights of the trains were increased, and the powers of the locomotives developed, to meet the ever-growing demands. The ordinary pneumatic brake was superseded by the rapid-action brake, and still more recently by pneumatic brakes of still more rapid action. In spite of the great number of brakes that have been devised, and notwithstanding the variety of their details, a classification is a simple matter. Practically every one of any importance depends for its action and its braking power upon the use of either compressed air, or of rarefied air—that is, upon a vacuum.

A continuous pneumatic brake comprises the following essential parts:—

1. A steam-driven pump upon the locomotive, to compress or extract the air in the system.
2. An air pipe carried throughout the length of the train, and connected between the vehicles by means of air-tight couplings and sections of flexible tubes.
3. A valve on the locomotive near the mechanic, to control the air pressure in the pipe.
4. A brake cylinder under each vehicle, connected either directly or indirectly to the air-supply pipe.

In each brake cylinder is fitted a piston or a movable diaphragm, open always to the atmosphere on the one face and to the compressed air or to the vacuum on the other face, when the controlling valve on the engine is operated. The difference of pressure on the piston forces it out, and thus operates the levers upon which the brake shoes are carried, the pressure exerted by the shoes upon the wheel rims being dependent on the multiplying effect of the levers between the shoes and the brake piston.

Continuous pneumatic brakes may be divided into the two general classes:—

1. Vacuum brakes.
2. Compressed-air brakes.

Each of these classes may again be subdivided into two entirely distinct groups, according as their action is direct or automatic. There are thus four fundamental types of continuous pneumatic brakes:—

The direct vacuum brake.
The automatic vacuum brake.
The direct compressed-air brake.
The automatic compressed-air brake.

A pneumatic brake is said to be direct when the air-supply pipe is open to the atmosphere while the train is in motion and the brakes are off. When the brakes are to be applied, the air pipe is opened to the compressed-air supply reservoir or to the vacuum, a difference of pressure is established on the two sides of the brake-cylinder diaphragm, which moves outwards and forces the brake shoes against the rim of the wheel. To remove the brakes, the air pipe, and therefore the brake cylinder, is again put into communication with the atmosphere. It is evident, therefore, that a brake of this type is of the simplest possible nature, requiring only a brake cylinder under each vehicle connected to the air-supply pipe by flexible tube connections. The remaining mechanical parts, such as the levers and shoes, are common to all the types.

There is a further advantage in the ease with which the direct brake can be applied, either gently or with its full power, whenever desired. By manœuvring the inlet valve of the supply pipe, the pressure difference in the cylinder may be varied at will, and

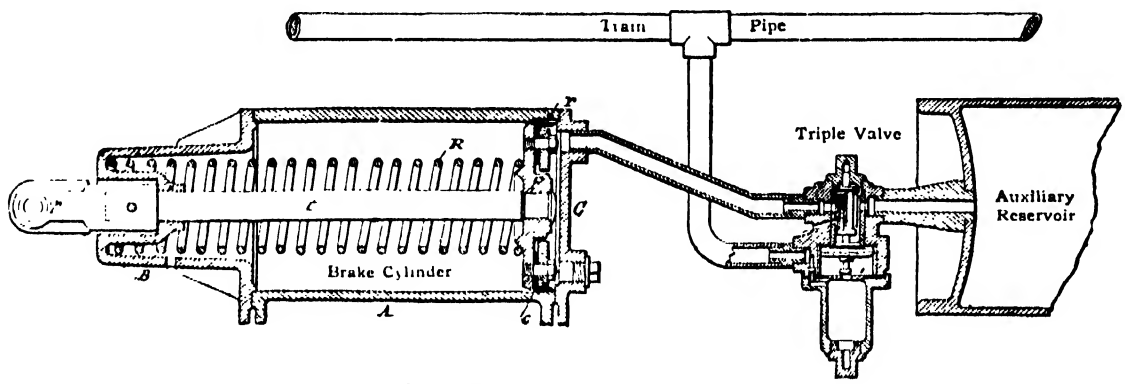

Fig. 201.—Westinghouse Automatic Compressed-Air Brake

the brakes applied gradually with any force up to the maximum. In the reverse operation of removing them the same applies. The pressure may also be reduced until the wheel just grips and slips, which in practice is found to be a very efficient way of dissipating the energy.

In the automatic brake, on the other hand, the air-supply pipe is open to the compressed air or to the vacuum when the brakes are off and the train is in motion. It is by relieving the pressure or by destroying the vacuum in the air pipe, as happens when it is opened to the atmosphere, that the attendant is able to apply the brakes. Under each vehicle is placed not only a brake cylinder, as in the case of the simple direct arrangement, but in addition a storage chamber called the auxiliary reservoir, and a distributing valve which is in communication with the main air pipe and controls the passage between the brake cylinder and the reservoir. As in the former case, a controlling valve is placed on the engine beside the mechanic, by means of which he may put the main air pipe in communication with the supply of compressed air, or with the vacuum pump when the brake is of the vacuum type. Fig. 201 shows diagrammatically the arrangement of the Westinghouse automatic compressed-air brake, with its brake cylinder, auxiliary reservoir, and distributor, called in the diagram the triple valve. This distributor contains an arrangement of sliding pistons or valves, which moves under the action of the compressed air into such a position that the

reservoir is placed in communication with the air-supply pipe, while the brake cylinder is opened to the atmosphere. When these conditions exist the brakes are off, since there is no difference of pressure on the two faces of the diaphragm, which are both exposed to the pressure of the atmosphere alone. The auxiliary reservoir, on the other hand, is in communication with the main air pipe, and is becoming charged with compressed air or evacuated, according to the type of the brake. In general the capacity of the reservoir is from five to six times the volume of the brake cylinder when the diaphragm is in its extreme working position. To apply the brakes, the attendant by means of his controlling valve opens the air-supply pipe to the atmosphere, and thus reduces the pressure or the vacuum. This alteration of pressure changes the positions of the piston valves in the distributor in such a way that the communications between the air pipe and the reservoir, and between the brake cylinder and the atmosphere, are closed, while the passage between the auxiliary reservoir and the brake cylinder is opened. The piston is then acted upon by the compressed air stored in the reservoir, or by the vacuum, with a pressure which depends on the ratio of the initial volume of the reservoir to the final combined volume of the brake cylinder and reservoir. This may readily be calculated as follows. Suppose, for example, that V represents the volume of the auxiliary reservoir, while v represents that of the brake cylinder, and that P represents the pressure per square inch in the reservoir, and p the final pressure per square inch in the cylinder. When the brake is operated, the air which occupied an initial volume V will fill a final volume $V + v$; and since the pressure of a gas multiplied by its volume at the moment is constant, it follows that $p(V + v) = P(V)$, that is, $p = \frac{PV}{(V + v)}$. Knowing, therefore, the initial air pressure, the volume of the receiver, and the maximum working volume of the brake cylinder, the final pressure on the diaphragm may be calculated. To remove the brakes again, the mechanic by means of his controlling valve charges the air pipe with compressed air, or creates in it a vacuum. This brings the distributor valves to the original positions, in which the air-supply pipe and the auxiliary reservoir are in communication, and the brake cylinder is open to the atmosphere. Automatic brakes of this nature are much more rapid in their action than the direct-acting type, particularly on their application. To actuate them, all that is necessary is to create a difference of pressure, and consequently to move only the comparatively small quantity of air in the supply pipe, which generally is of a very small diameter. In the direct brake, on the other hand, the volume of air to be dealt with is not only that of the air pipe, but also the volume in the brake cylinders. As a result of this feature it is possible to use the automatic brake on trains composed of many vehicles, where the use of the direct brake would be quite impracticable.

In the case of accidents in which the air pipe becomes ruptured, as, for example, when the carriage couplings break, or in a collision, the behaviour of the two types of brakes is very different. Under such circumstances the direct brake is put completely out of action, since both sides of the brake pistons are at atmospheric pressure. It is impossible also for the attendant to apply them, because, the tube being open to the atmosphere, he cannot create in it the necessary pressure or vacuum. Any rupture

of the automatic-brake air tube, on the other hand, results in the sudden application of the brakes with their full available force. This braking action takes place on every vehicle fitted with a brake cylinder, and is quite independent of any action of the mechanic. From the point of view of safety alone the automatic system is therefore much superior to the direct-acting brake. If, for example, the train is standing, and while in this state is run into with sufficient force to break the couplings, the brakes on the separated portions of the train apply themselves automatically, and reduce the effects of the collision to a minimum. Or again, if the couplings of the train break when on an incline, the rear portion is prevented from running backwards, owing to the application of the brakes on all the vehicles. If the direct-acting brake alone were used the brakes would remain off, and could not be applied by the brakesman. The train would then run backwards down the incline with ever-increasing speed, and would probably wreck itself at the bottom. A further advantage of the automatic brake lies in the certainty with which any small defect makes itself evident; any leakage on any part of the system results in the application of the brakes, or, when slight, in a noticeable reduction of the pressure or vacuum in the air main. When, therefore, any defect makes itself apparent, the attendant is compelled to give it his immediate attention. With the direct brake, on the other hand, if between two applications of it a rupture of the pipe takes place, the mechanic receives no warning of the important fact that he has no longer any control over the train. Direct-acting brakes are generally used alone for only the slowest kinds of traffic, or for trains composed of very few vehicles. For trains of a considerable length, or where security against accidents is essential, the automatic brake is always fitted.

From the descriptions already given of the mechanical details of the two systems, it will be evident that the direct brake has the advantage of being less costly to instal or to keep in working order.

In a later section the more generally used types of brakes will be described in some detail, such, for example, as the Soulerin direct-vacuum brake, the Clayton automatic brake, and the several types of ordinary quick-acting and extra-rapid brakes manufactured by the Westinghouse Company; but before entering upon these details some consideration must be given to the arrangement and adjustment of the more or less complicated system of levers by means of which the force exerted in the brake cylinder is applied to the rims of the wheels. The problems involved in the braking of trains will be considered also from the theoretical point of view, and simple formulæ will be derived by means of which the forces brought into action in ordinary daily working may be determined.

THE BRAKE GEAR AND ITS ADJUSTMENT

In the arrangement of the levers and gear there is infinite variety, from the simple arrangement of one shoe, applied by means of a hand lever, to the more complex systems of levers necessary when the vehicle runs on two bogies each with four wheels fitted with brake shoes. It is generally necessary to operate these levers by means of either

a screw and hand wheel, or by means of the usual brake cylinder; the one method of control being independent of the other, and therefore available as a reserve in special circumstances. Suitable links are inserted in the gear, so that the operation of the brake shoes by the one arrangement will not be affected by the other. Two examples are given, in figs. 202 and 203, of the gear required for eight brake shoes. In the one case the brakes are operated by compressed air acting upon pistons lying horizontally and working in opposite directions in the brake cylinder, while in the second a vacuum

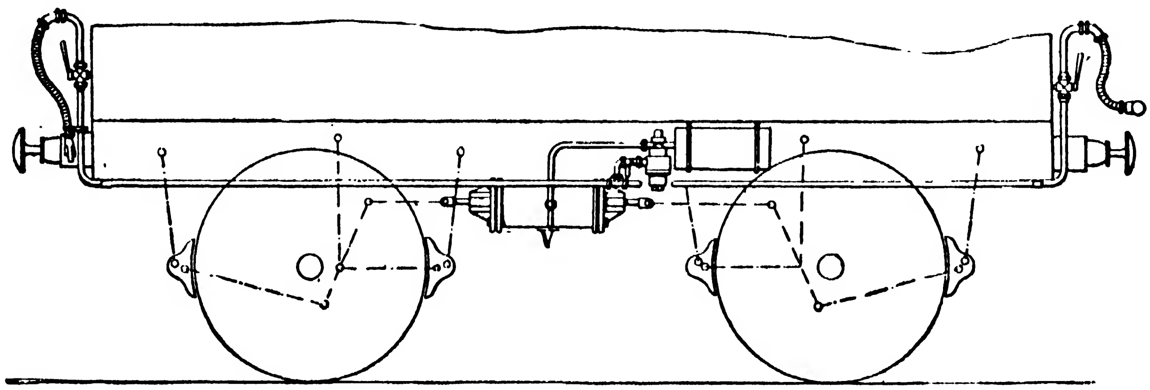

Fig. 202.—Arrangement of Compressed-air Brake Gear

cylinder placed vertically is used. This latter arrangement, illustrated in fig. 203, combines also the hand-screw brake already mentioned, the connecting link which permits of the independent working of the two systems being shown clearly in the figure at P. Some provision must be made for the exact adjusting of the shoes relatively to the wheels. Owing to the multiplying effect of the system of levers between the brake piston and the shoes, their motions will be inversely proportional to one another. When, for example, the diaphragm is caused to move, by a difference of pressure on its two faces,

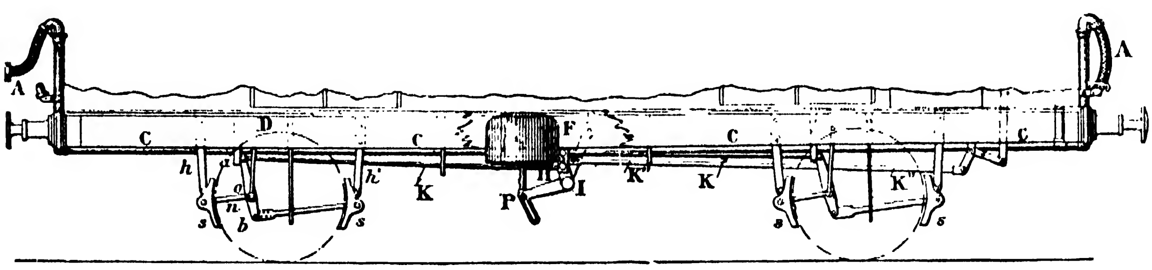

Fig. 203.—Arrangement of Vacuum and Hand Brake Gears

through a distance of, say, 5 in., the shoes will move only $\frac{1}{2}$ in. if the multiplication of the levers is in the ratio of 1 to 10; that is, the total force on the air-cylinder piston will be applied with tenfold effect at the wheel rim, while the actual motion of the brake blocks will be only one-tenth of that of the piston. Unless some provision were made for the adjustment of the shoes, they would fail to grip the wheels as soon as the wear of the blocks and tyres amounted to about the $\frac{1}{2}$ in. of total motion. Certain of the levers are fitted accordingly with turn-buckle screws, or with adjusting holes and pins, so that the piston may be set at its full-out position when the shoes are

separated from the tyres by the correct amount, and in this way the wear of the blocks and gear may be taken up as required. It will be evident that the repetition of this adjustment is limited by the thickness of the shoes. When these become worn beyond a certain point they must be replaced with new ones, which may be very readily done. Careful adjustment of the gear is of the greatest importance, and can be best carried out in safety and with sufficient ease when some such special provision is made as, for example, the ingenious and simple arrangement devised by the French engineer Chaumont.

The Chaumont Gear. Two purposes are served by the Chaumont gear, which may be considered as consisting of two separate mechanisms. The one portion serves merely as an indicator of the amount of the wear, while the other portion enables the wear recorded to be taken up. The indicator portion is very simple. It consists of a scale fixed on the frame of the vehicle, and of a pointer movable along it and connected to the brake piston by some direct and simple arrangement of levers or other mechanical device. On the scale, figures are engraved from 0 to 20. When the pointer is at 0 the brake should be in the off position, and when the brakes are applied with sufficient force to bring the piston of the brake cylinder to the end of its normal travel, that is, when the brake is full on and in good working condition, the pointer should indicate the mid point 10 of the scale or thereby. If the pointer travel exceeds this, and particularly if it approaches 20, the piston travel has apparently become too great, and requires to be corrected. By inspection of the indicators on the vehicles, when the brakes are being tested before the train leaves the station, the attendant may satisfy himself as to the actual condition of the gear without having to creep under the carriages, as would otherwise be necessary. Other interesting information is furnished by the indicator, but the principal points mentioned below will be better understood when the description of the compressed-air brake has been read.

1. **Bending of the Levers and Backlash.**—Suppose that the pointer comes opposite 10 on the scale when air at a moderate pressure is admitted to the cylinder, and that when the full air pressure is admitted the pointer moves farther towards 20; this indicates some abnormal bending of the levers due to defects or weakness, or to lost motion in the joints. The extra travel of the piston can only be accounted for by some such defect of the gear, since in the first instance the brake shoes are brought by the moderate pressure to the end of their travels against the wheel tyres.

2. **Stoppage of the Air-Escape Passages.**—A very small quantity of air admitted to the brake cylinder should escape readily through the exhaust tube without moving either the piston or the pointer, which should remain standing at 0 or return quickly to zero if it did move. If, however, the pointer moves, the exhaust passage is most probably choked, a defect which results in sudden and disagreeably jerky action of the brakes during the running of the train.

The Chaumont adjusting arrangement is entirely separate from the indicator portion, and is not much more complicated in its action. Any of the ordinary brake gears, whether composed of a simple or a complicated system of levers, may be adjusted by lengthening one or other of the coupling rods until the shoes are in contact with the tyres. When in this position the brake piston should theoretically

have only a very small space to move through in order to bring the full force upon the shoes, provided the gear is quite rigid. In practice this is not so, since there is always some lost motion, due to cumulative bending, which may be very slight in the individual parts, and to slackness at the joints. When the brakes are in the off position it is essential that the shoes should be quite clear of the wheels, otherwise there will be serious wear and loss by friction; about ¼ in. of clearance should be allowed between them and the wheels. This may be effected by means of a screwed connection or a turn buckle on one of the rods, or by a coupling pin and suitable holes spaced 1 in. apart on overlapping portions of one of the levers, which may thus be shortened or lengthened as desired, to give the necessary clearance between the shoes and tyres. Adjustments of this nature are both difficult and dangerous to carry out satisfactorily, and there is the further danger, when screwed connections are used, that they may slack off during the running of the train, especially considering the very unfavourable conditions under which the gear is required to work. The essential features of the Chaumont adjusting gear are as follows:—At some suitable point, depending upon the particular arrangement of the levers, is placed a screwed rod provided with a bevel wheel or worm, by means of which it may be turned. A nut working upon the screw is coupled to one of the levers by means of a link, so that when the screw is rotated the nut moves to or fro as the case may be, carrying with it the lever, and thus advancing or withdrawing the shoes from the tyres of the wheels. The bevel or the worm wheel on the screw may be operated from convenient positions at the ends of the vehicle by suitable arrangements of shafts and gear wheels. Generally the ends of the shaft are provided with hand wheels, or are squared to take a turning key, so that the attendant may adjust the shoes whenever the indicator shows this to be necessary. In practice the adjustment would be done by first moving the shoes into firm contact with the wheels, and then withdrawing them the necessary ¼ in. by turning the shaft through several revolutions—usually about three.

The nature of the whole arrangement is so simple as to require no further description. It has been installed in one form or another by most of the principal railway companies on the Continent.

TRAIN BRAKES CONSIDERED DYNAMICALLY

When the brakes are applied to the wheels of a train moving at a certain speed, there is a certain force F between the shoes and the tyres which tends to prevent rotation of the wheels, and retards the motion of the moving mass. This retarding force F is not merely the pressure Q of the shoes on the tyres, but is a force represented numerically by the product Qf_1 where f_1 is the coefficient of friction between them. If, again, P represents the fraction of the total load carried by a particular wheel, P will represent the force with which the wheel bears upon the rail, while Pf_3 will represent its adhesion force at the rail. So long as Qf_1 is less than Pf_3 the wheel will continue to rotate; as soon, however, as Qf_1 is made to exceed Pf_3 by increasing the pressure of the brake shoes on the tyres, the wheel ceases to rotate, or, as it is called, becomes locked. The

force Q between the locked wheel and brake block now plays no part in the dissipation of the energy of the moving train. The retarding force is now between the wheel slipping along the rail, and may be represented by Pf_2, where f_2 is the coefficient of friction between the wheel and rail. It will be evident that if the train is upon an incline of such steepness that the component of the weight of the train along the direction of the rails exceeds the total retarding forces at the wheels, the train could not under such circumstances be prevented by the brakes from slipping backwards down the incline. This is the most serious danger the driver has to fear on an incline. The only means of increasing the braking action consists in momentarily relieving the brakes, and then again applying them with a pressure just sufficient to lock the wheels intermittently and not completely. It is found in practice that the kinetic energy of the train is more rapidly dissipated as heat at the brake shoes in this way than at the rails when the wheels are completely locked. This applies also to all public vehicles on rails, such as tramway cars. Many accidents of this kind on steep roads have been accounted for by the drivers as due to the failure of the brakes to act, when in reality the whole blame is due to the too sudden and forcible application of the brakes, which have acted too well rather than not at all. The force Qf_1 should reach as nearly as possible the value of the force Pf_3, but should never be allowed to equal it, because at this point the wheels cease to rotate, and slipping on the rails commences. Apart from the danger which this involves, there is the further objection that the wear of the tyres becomes very irregular. Flats are formed instead of the whole surface being worn away uniformly, and, further, the wear takes place on the rails and wheels instead of the brake blocks, which may more readily be renewed. Since Qf_1 should not exceed Pf_3, the value of Q beyond which it is not advisable to go is $\frac{Pf_3}{f_1}$. Considering the importance of the subject, it is of the greatest interest to know the value of these coefficients, which are by no means easily determined. A long and very expensive series of experiments was carried out in 1878 to 1879, on the London, Brighton, and South Coast Railway, by Mr. George Westinghouse and Captain Douglas Galton. Using different materials for the brake blocks, tyres, and rails, they were able to compile tables showing in what manner the coefficients varied under different circumstances. They also very definitely determined the laws governing the theory of brakes as used on railway vehicles.

According to Galton's results, a continuous brake to approach perfection should fulfil the following requirements:—

1. It should act upon all the wheels.
2. It should be capable of acting on all the wheels of the train instantly, and with the maximum power, if the greatest possible retarding force is to be obtained.
3. The shoes should be adjustable to suit the normal speed and other conditions, so that the force at the brake blocks may as nearly as possible equal but never exceed the adhesion at the rails. In this way only can the maximum braking action be obtained.

4. The force with which the brake shoes are applied should be variable at will to any degree between zero and the maximum.
5. It should be capable of repeated application at very short intervals, and of continuous application on an incline.

A brake of this kind, which acted simultaneously and uniformly on all the wheels of the train, would stop the motion with perfect smoothness, and would require to be applied for the shortest possible time. These ideal conditions are not attainable in practice, since the wear of the brake shoes is more or less irregular throughout the train, and, further, simultaneous action is not obtainable owing to the appreciable time taken by the air to traverse the length of the train pipe. With an ordinary brake this interval amounts to from $\frac{1}{8}$ to $\frac{1}{3}$ second between one vehicle and the next. Notwithstanding the difficulty of attaining perfection in practice, it is essential for the efficient working of the brake to keep the adjustment of the brake shoes as uniform as possible throughout the train, and to remove every resistance to the passage of the air. When dealing later with the rapid-acting brake, it will be shown that all later improvements have been directed to the reduction of the time taken by the air in passing between vehicles. As for the adjustment of the shoes, nothing further need be added here, as the very simple and ingenious arrangement of Chaumont already described meets with sufficient completeness all the demands of actual service.

THE DIRECT VACUUM BRAKE

The Soulerin Brake.—When first the continuous brake was applied to trains, each of the two classes of brakes—compressed air and vacuum—had its strong partisans. In the United States, France, and the Continent generally, the compressed-air brake received most favour, while, on the contrary, the vacuum brake extended rapidly in Britain and its colonies, in Spain, and South America. Many of the smaller railway companies at the present time use the direct vacuum brake on their secondary trains for the reason already explained, that the first cost of the installation and the cost of its upkeep are less. In France the system most generally adopted is the Soulerin. It consists essentially of the same parts under each vehicle, as shown in fig. 204, supplied as before by means of a continuous air pipe connected between the vehicles by flexible couplings; that is, under each vehicle upon which the brake is fitted there is a cylinder with a flexible diaphragm cover, and connected directly to the train pipe through a cock, which serves on occasion to completely isolate the cylinder from the pipe in case of accident, as, for example, when a leak occurs in the diaphragm. On the engine itself there is placed an ejector combined with a controlling valve and handle. This part of the gear, shown in fig. 205, is fixed to some convenient part of the engine by means of the bracket R. Steam is taken generally from the top of the dome to ensure its dryness, and after passing a small regulating stop cock, enters the ejector at V. At C connection is made with the train pipe, and from M a connection is led to a vacuum gauge. The controlling valve operated by the lever *m* consists of a circular seating

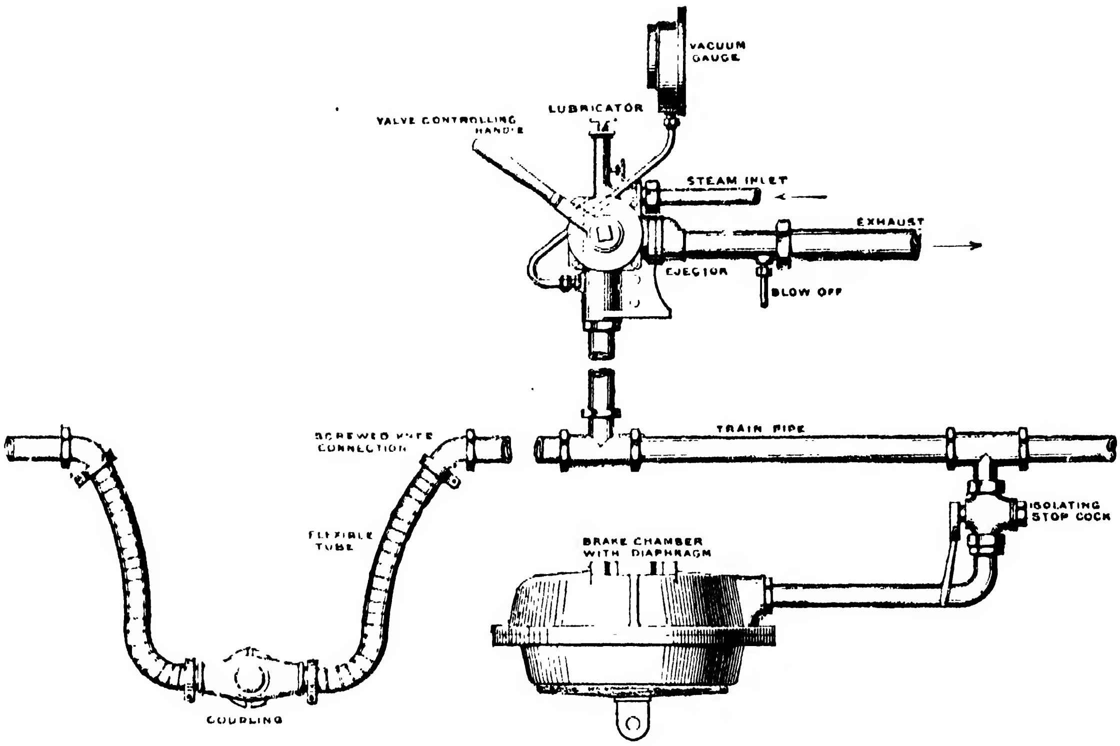

Fig. 204.—The Soulerin Brake

with suitable ports, and of a disc working upon it and provided with corresponding apertures. In the three positions of this hand lever the ports are opened and closed

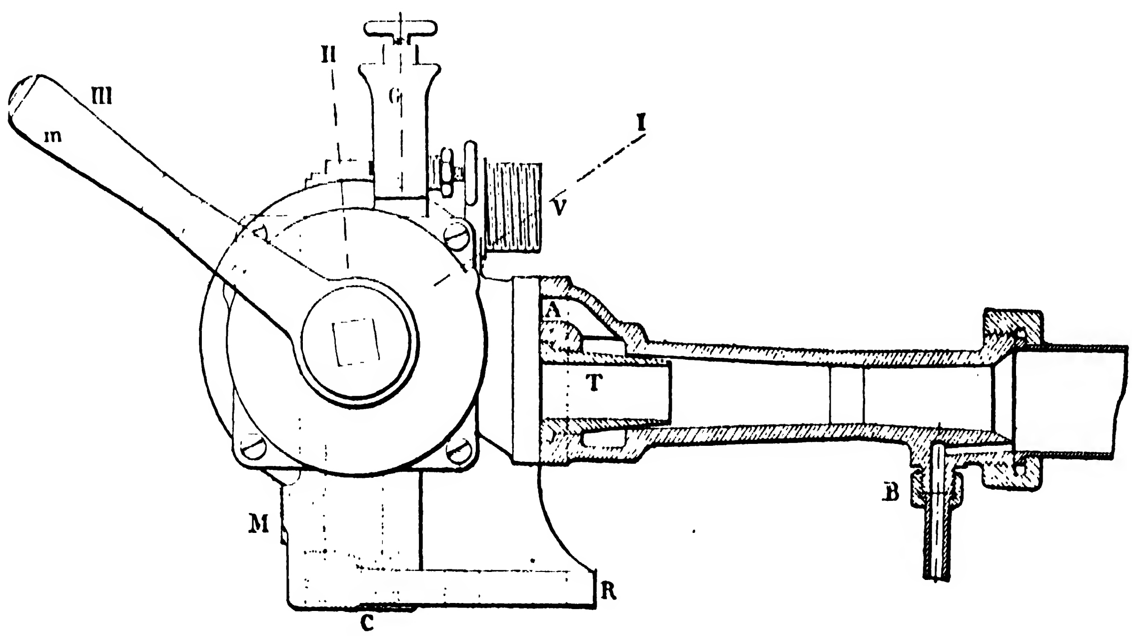

Fig. 205.—Controlling Mechanism of the Soulerin Brake

as required, to give the necessary distribution of the steam and air. G is a lubricator for the disc valve.

By means of suitable index marks, the controlling lever may be placed in any one of three positions, I, II, III.

I is the "brakes on" position, in which steam is admitted to the ejector, and all communication between the train pipe and the external air is closed by the controlling valve. The jet of steam then produces a vacuum in all the brake cylinders and throughout the train pipe.

II is the "rest" position. Steam is cut off from the ejector, while communication between the outside air and the train pipe still remains closed.

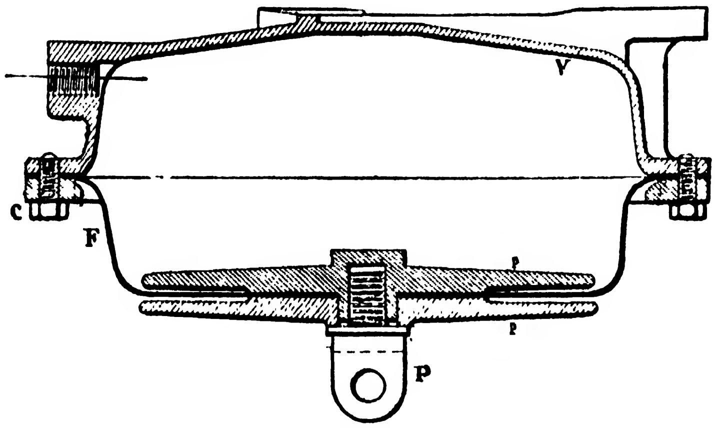

Fig. 206. Section through Brake Cylinder of Soulerin Brake

III is the "brakes off" or release position, in which steam is still cut off from the ejector as in II, but the train pipe is open to the atmosphere.

The ejector is placed horizontally, as shown in section in fig. 205. Steam enters at A, and passes as an annular jet through the space between the tube T and the outer casing. In its passage the jet sucks the air from the train pipe through the tube T,

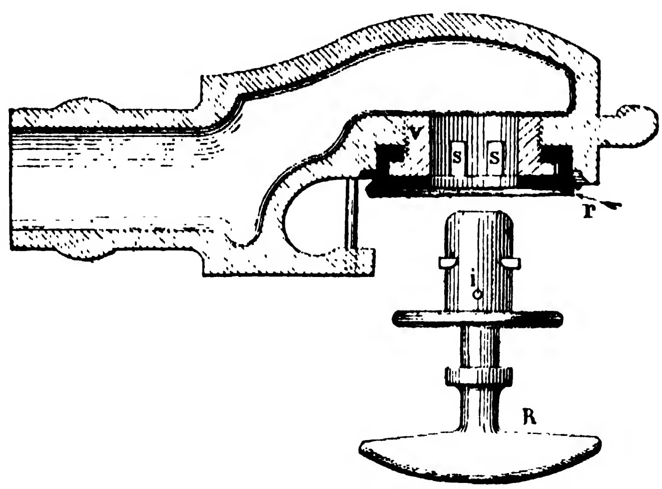

Fig. 207.—Train Pipe Coupling with Stopper

and discharges it through the exhaust to the atmosphere. A small pipe B, opening into the exhaust through a very small aperture, serves as an overflow to drain off the condensed steam. Fig. 206 is a section through the brake cylinder, which consists of a metal casing V enclosed by a flexible diaphragm of strong indiarubber F fixed to the casing by a ring C held in position by screws. Two plates *pp* are provided, one on each side of the diaphragm, to which the brake levers are coupled by a link at P.

The coupling piece T, shown in figs. 207 and 208, is fixed on each of the flexible tubes at the ends of the vehicle. They are of the Westinghouse type, and interchangeable with the couplings of trains fitted with that system. Air-tightness at the faces of the two coupling heads is secured by means of the rubber washers *r*, held in position by brass glands V. When the two heads are engaged with one another, their rubber face-rings are squeezed tightly together, so as to form an air-tight joint. In the case of the last coupling on the train it is necessary, in order to hermetically close the pipe and prevent the entrance of grit, to provide the stopper R, which consists of a plug *i*, with a flange greater in diameter than the rubber ring *r*. Two lugs on the plug portion *i* engage with projections S S on the inside of the gland V when the stopper is inserted, so that it may be screwed tightly home.

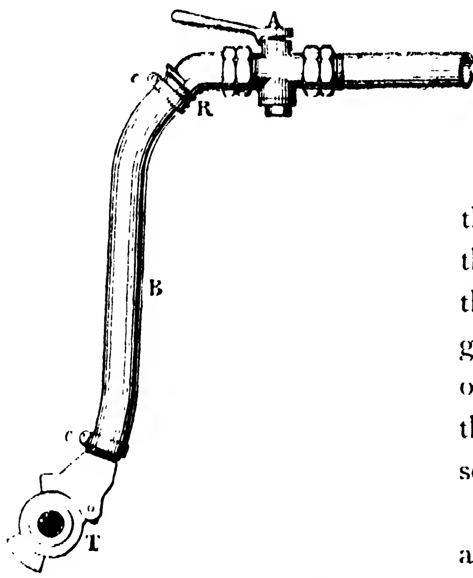

Fig. 208. Flexible Coupling Tube

Fig. 208 shows the arrangement of the coupling at the ends of each vehicle. A is a stop cock to isolate when necessary any part of the system, B is a flexible tube composed of rubber cloth and secured by clamps *c c* to the knee piece R at one end and to the coupling head T at the other. When the projections on the heads are made to engage, and then rotated through about a right angle, the rubber jointing rings become squeezed together and so form an air-tight joint.

THE AUTOMATIC VACUUM BRAKE

The Clayton Brake of the Vacuum Brake Company.—On the British and Colonial railways, and in Spain and South America, the automatic vacuum brake is more universally used than the direct type, and of the several systems the Clayton brake, as made by the Vacuum Brake Company, is probably more generally used than any other. In fig. 203 the whole of the gear required on one four-wheeled vehicle with eight brake blocks is shown. Fig. 209 shows the train pipe and the cylinder with its connections, but without any of the brake levers. C C is the train pipe, with its flexible couplings A A and the coupling heads T T closed by their stoppers, as they would be if the

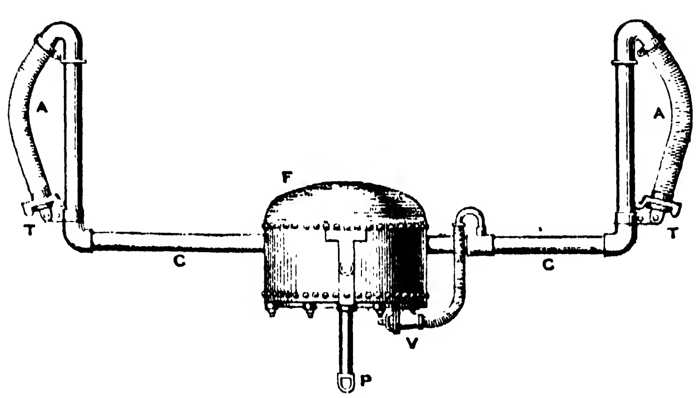

Fig. 209. Vacuum Brake Cylinder and Train Pipe

vehicle were isolated. A pin P on the head of the piston rod of the brake cylinder F engages a link which forms part of a bell-crank lever P I H pivoted at I, as shown in fig. 203. Rods K K communicate the pull intensified by the bell crank to levers *a o b*, suspended from the body of the vehicle by links D, and connected through coupling rods to the brake blocks. The levers *a o b* still further increase the forces with which the shoes are pressed upon the wheel tyres. The shoes *s* swing at the ends of suspending links *h h'*. To the end of the lever I H is also coupled a rod K″, operated from some convenient position by means of a hand wheel and screw, so that the brakes may be applied by the brake cylinder or by the hand gear quite independently of one another. This is made possible by the addition of a link on the end of the bell crank lever, in which the pin of the brake piston is free to move. When the cylinder acts, the piston pulls the short arm of the crank lever and applies the brake blocks. When, on the other hand, the screw gear is operated, the long arm of the crank is pulled and the shoes applied as before, while the link on the short arm of the crank rides idly over the pin P without affecting the brake piston in the cylinder. In this way the actions of the two brakes are absolutely independent. Referring again to fig. 209, which shows the essential parts of the automatic vacuum brake carried on the under frame of the carriage, C C is the train pipe, provided at each end of the vehicle with flexible portions A A attached to knee pieces. The coupling heads are shown fixed to their stoppers, as is necessary in the case of the last coupling, in order to close the end of the train pipe. F is the brake cylinder, carried upon trunnions, *t t* fig. 210, and P is the piston end, which communicates the motion to the brake levers. The cylinder F is connected to the train pipe by the small flexible pipe, and the opening into the cylinder is controlled by a ball valve V. Sections through the brake cylinder are given in figs. 210 and 211 to show the action of the ball valve and the piston. Instead of the diaphragm used in the Soulerin arrangement a deep piston M is used, with a face about 4 to 6 in. deep, upon which runs a circular rubber ring *a*. Flanges on the piston face prevent the ring from overrunning the ends. As the piston moves, the rubber rolls between the piston face and the cylinder walls *i i*, between which it is squeezed, and in this way a very air-tight joint is obtained without undue wear of the soft rubber. The cylinder is completely enclosed around the top by the sheet-metal cover C C, and at the bottom by a solid plate provided in the middle with a stuffing gland through which the piston rod works. At

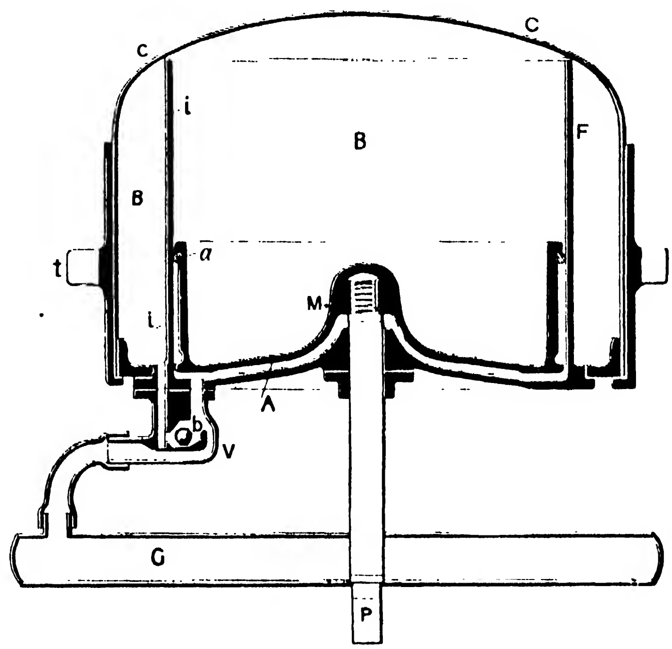

Fig. 210.—Clayton Brake Cylinder. "Brakes off" position

the lowest part of the cylinder is placed the ball valve V already mentioned. It consists simply of a ball *b*, free to move through a small distance in a channel so as to close or open the air passage. Fig. 210 shows the "brakes off" or running position of the parts, while fig. 211 shows the "brakes on" position, with the space occupied by the air at atmospheric pressure shown shaded. It will be clear from the figures that the space A under the piston is always of a comparatively small volume, and always in communication with the train pipe, while the space B B above is large, and may be made more so by the addition of a supplementary reservoir. This space B B is completely cut off from the train pipe whenever the small ball is driven by a difference of pressure against its seating so as to close the communication. During the running of the train, when the brakes are off, a vacuum is produced in the train pipe and also in the cylinder reservoir B B, since the ball *b* lies loosely in its channel. On the under side of the piston there is the same vacuum maintained, so that it is in equilibrium, and rests by its own weight in the lowest position. When the application of the brakes is desired, the vacuum is wholly, or at first partially, destroyed by admitting air to the train pipe. The rush of air forces the ball *b* on to its seating, where it is held by the difference of pressure on its two sides. Communication between the train pipe and the upper side of the piston, which remains at the low pressure, is thus cut off. Owing to the difference of pressure on its two faces the piston immediately moves upwards, and thus acts upon the brake levers with a force equal to the difference of pressure per square inch between the two sides of the piston multiplied by its area. It will be evident that satisfactory working can only be expected when the ball valve is in good condition and the stuffing gland *e* is tight. The initial pressure depends entirely upon the quantity of air admitted by the attendant to the train pipe, and he is able to vary the pull on the brakes to any extent, from a maximum to zero, by admitting the air suddenly or by successive amounts. It will also be evident from an examination of the figures that the initial pull will depend not only on the completeness of the vacuum formed in the reservoir, but also on the travel of the piston, that is, on the state of adjustment of the brake shoes. The greater this travel the greater the reduction of volume on the low-pressure side of the piston becomes. This decrease of volume means an increase of pressure, and therefore a reduction of the difference of pressure on the two sides of the piston. Faulty adjustment of the gear affects all automatic brakes, whether of the compressed-air or vacuum types, in the same way,

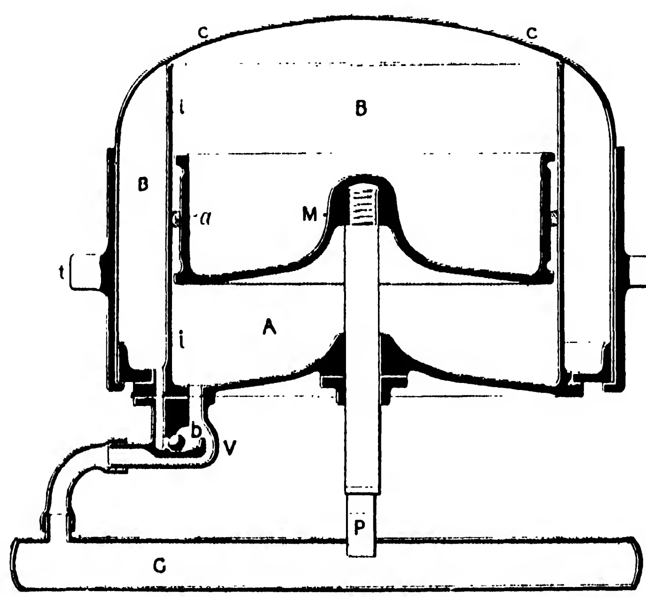

Fig. 211.—Clayton Brake Cylinder. "Brakes on" position

but the effects are of much greater importance in the case of the vacuum brake, in which the volumes are greater and the margin of pressure very much less than in the compressed-air brake.

To remove the brakes the attendant, by again producing a vacuum in the train pipe, allows the ball *b* to fall back and open communication between the two sides of the piston, which then descends by gravity and frees the brake blocks. Sometimes the descent of the piston is accelerated by the addition of a spring acting on one or other of the levers. To ensure good working of the rubber piston ring every care should be taken to guide the piston so that the action of the levers cannot cause it to tilt in the cylinder. A sufficiently long stuffing box and careful adjustment will help to remedy such a defect. It is, however, more customary to mount the brake cylinder upon trunnions, so that it may swing into a position to suit the twisting action of the gear.

Besides the gear already described, there is provided on the locomotive an ejector and hand-controlling valve, which differs from the simple ejector of the direct vacuum brake in that it is double, and consists of a large and a small ejector combined. The large ejector serves to rapidly exhaust the train pipe and the space under the piston when the brakes are off, while the small one is provided to maintain during the running of the train the vacuum when once produced. A certain amount of leakage always takes place at the numerous couplings and joints, and this requires to be compensated by the constant use of the supplementary ejector, in order to prevent the brake blocks from gradually working into contact with the wheels.

The Westinghouse Brake. — The Westinghouse automatic vacuum brake resembles the Clayton brake, with this essential difference, that for the piston is substituted an indiarubber diaphragm, as in the Soulerin design, and that in addition to the ball valve a separate spring-controlled valve is added to ensure still further the air-tightness of the air chamber and reservoir. The supplementary valve is held on its seat by a spring, which may be adjusted to press as strongly as desired without in any way affecting the working of the brake. Fig. 212 is a section through the cylinder, and shows clearly the arrangement of the various details. It consists of a chamber formed by an upper and a lower casing, between the faces of which is clamped an indiarubber diaphragm D, which again is clamped in the centre between two plates forming the head of the piston rod A, to which the first brake lever is coupled. As before, the rod works in a stuffing box P, cast in one part with the lower casing, upon which is bolted a separate casting carrying the valves. H is the ball valve, and G is the supplementary valve, held upon its seating by the spring K. It will be seen that a space F of the minimum volume is obtained under the diaphragm, while the space E above the diaphragm is very large. The volume of the brake chamber may be still further increased as desired by means of an auxiliary reservoir connected to the chamber by the pipe R. One end of the lever LL′, pivoted at O, engages the spindle of the valve G, while the other end presses upon the under side of the diaphragm plate. When the diaphragm descends to its lowest position it depresses the one end of the lever and raises the other, and with it the valve G. Communication between the two sides of the diaphragm takes place through the passage I I, formed in the wall of the

lower casing, and through the ball and lift valves H and G, while direct communication between the train pipe and the lower chamber F takes place through the pipe shown dotted at C. The action of the brake is as follows:—During the running of the train a vacuum is formed in the train pipe and through the connection C in the lower chamber F. Communication between the upper and lower chambers E and F then takes place through the valve K, held open by the lever L L′, through the ball valve H, which is raised from its seat under the difference of pressure, and through the passage I I. The vacuum is then formed also in the upper chamber E and the auxiliary reservoir, equalizing the pressures on the two sides of the diaphragm, which rests at the bottom

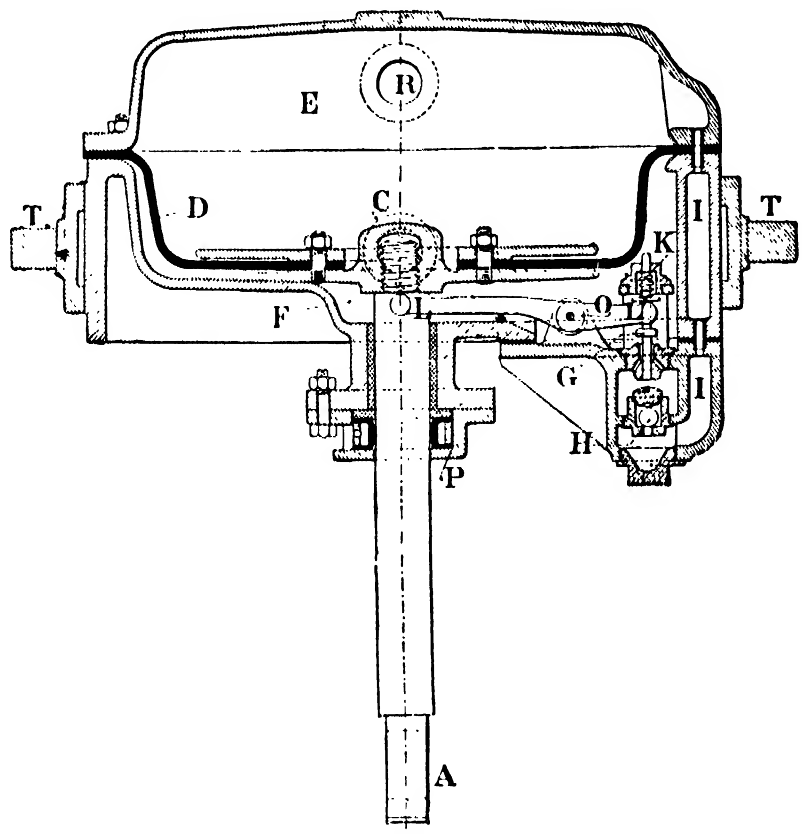

Fig. 212.—Westinghouse Vacuum-Brake Cylinder

of the chamber by its own weight. On the application of the brakes the admission of air to the train pipe increases the pressure in the lower chamber F and forces the ball valve H upon its seat, closing all communication between the upper and lower sides of the diaphragm, which is then forced up to the top of its travel. The rise of the diaphragm frees the lever L L′ and allows the valve to close under the action of the spring K, which is made sufficiently strong to ensure air-tightness. To release the brakes again, the admission of air to the train pipe is stopped and the vacuum re-formed in the pipe and the lower chamber. Under the action of its own weight, and of the weights of the brake levers and releasing springs, the diaphragm sinks again to its lowest position, where it acts upon the lever L L′, thus raising the valve G. The vacuum is then produced through the whole system. It will be seen that the control of the braking force is complete both in the On and the Release positions, since

at any moment the force with which the brakes are applied depends upon the extent of the vacuum formed in the train pipe and the lower chamber. On the locomotive is placed in addition the combined double ejector and manœuvring cock illustrated in fig. 213, which serves the same purpose as the Clayton ejector already mentioned. The large ejector has an annular steam jet as shown, and aspirates the air through the central pipe, while the small ejector beneath it has a central jet, and draws the air through the annular space around it.

The Soulerin Brake.—The Soulerin brake consists of a separate brake cylinder, auxiliary reservoir, and train pipe, and acts upon the automatic vacuum principle, as in the case of the Clayton brake. It is, however, more analogous to the Westinghouse

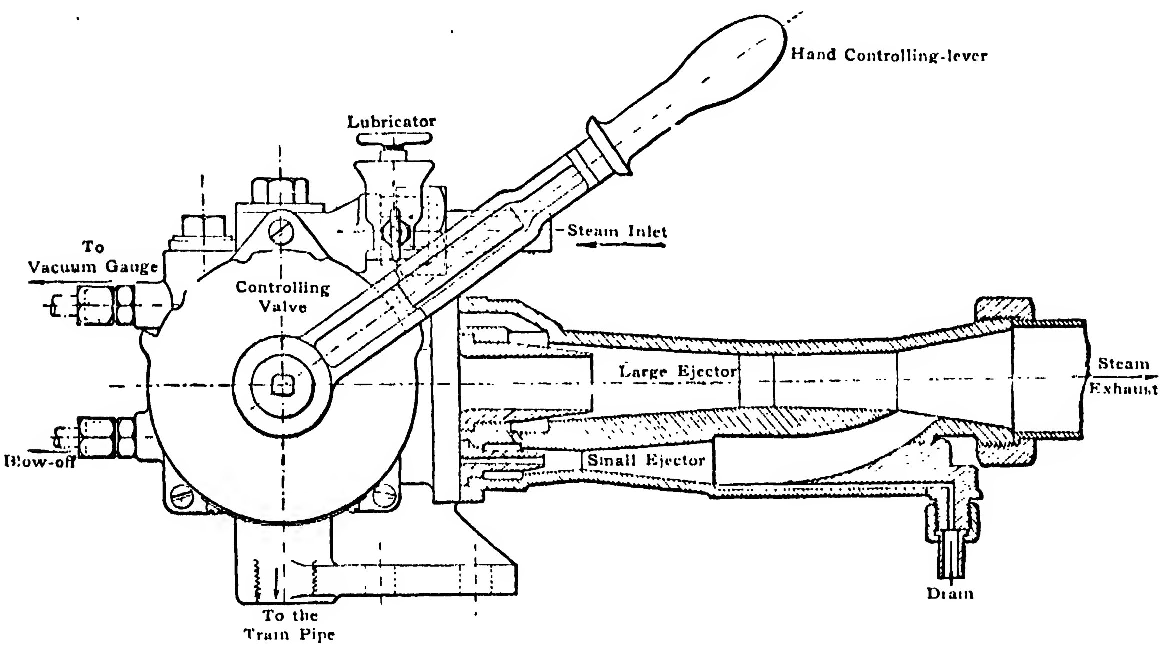

Fig. 213.—Westinghouse Ejector and Controlling Valve

compressed-air brake, while the Clayton brake resembles the Wenger brake described later. The action of the Soulerin brake is in general the same as that of the Westinghouse, that is, during the running of the train a vacuum is formed in the train pipe and in the auxiliary reservoir, while the brake cylinder is open to the atmosphere. When the vacuum is wholly or partially destroyed in the train pipe, the valves of the distributor move so as to isolate the train pipe and to place the brake cylinder in communication with the exhausted auxiliary reservoir. In this way the brakes are applied. The distributor resembles in principle the triple valve of the Westinghouse compressed-air brake, but differs from it in arrangement and in detail. The brake cylinder may be of the diaphragm type used in the direct vacuum system already described, or it may have the piston and rubber-ring arrangement shown in fig. 210.

AUTOMATIC COMPRESSED-AIR BRAKES

Westinghouse Ordinary Type.—Fig. 214 shows diagrammatically the parts of the brake that are carried upon each vehicle, viz.:—

The train pipe E, which is a tube of about 1 in. internal diameter.

Two flexible couplings, one of which, K, is shown.

Two stop cocks N, one at each end of the vehicle.

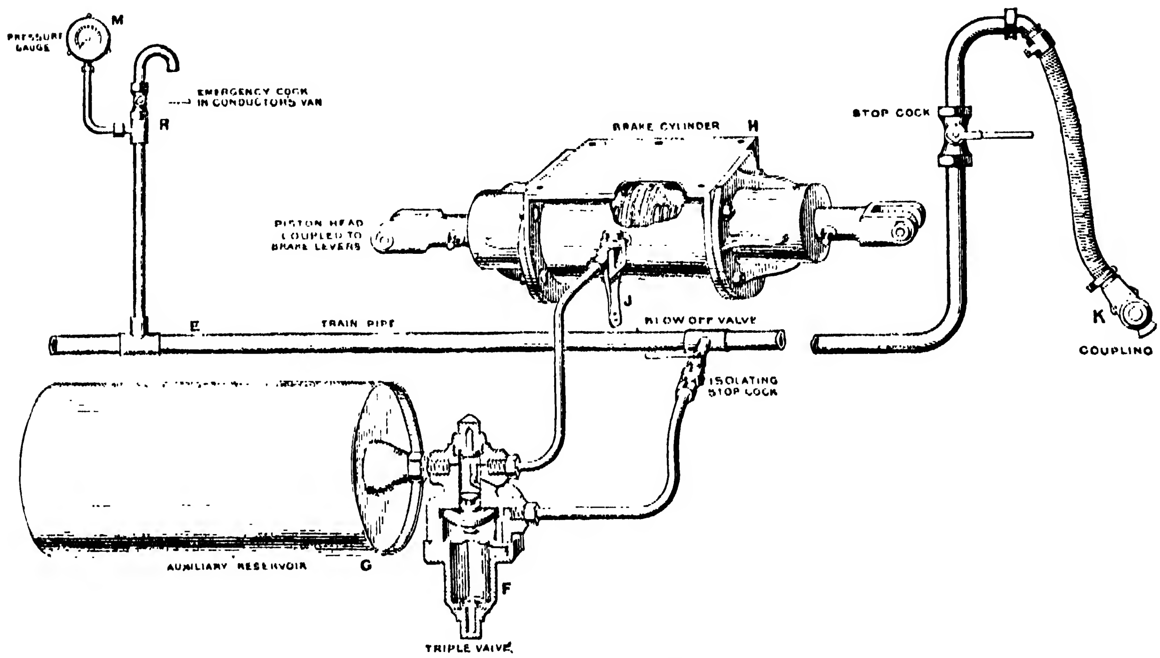

Fig. 214.—Arrangement of Westinghouse Ordinary Brake

A brake cylinder H, with one or with two pistons according to the requirements of the vehicle.

A distributor or triple valve F.

A stop cock between the air pipe and the triple valve to isolate the system on any vehicle in case of break-down. The train pipe then acts simply as a communication past the isolated gear to the next vehicle.

Lastly, a hand emergency valve J, to permit of the brakes being released by hand in cases where they have been accidentally applied, usually with great force, as when the air pipe ruptures or the triple valve fails to act in the proper way.

In addition to these parts the locomotive is provided with the following arrangements, shown in fig. 215:—

The steam-admission cock T.

A steam-driven air compressor.

A main reservoir G, having a capacity of about 10 to 15 cu. ft.

An operating valve D, and a pressure gauge L.

Operating valves of many different designs are in general use. In certain cases, as, for example, on the guard's van, there is fitted a gauge and brake cock communicating with the train pipe. The guard is thus able to satisfy himself at any moment as to the state of the vacuum in the whole brake system.

Having now described the general action of brakes of this type, it remains only to describe very briefly the gear provided for the production of the pressure and the triple or distribution valve.

The pump shown in fig. 215 consists of a steam cylinder A and an air compressor B, arranged in tandem with the two pistons on one piston rod. Steam is distributed to

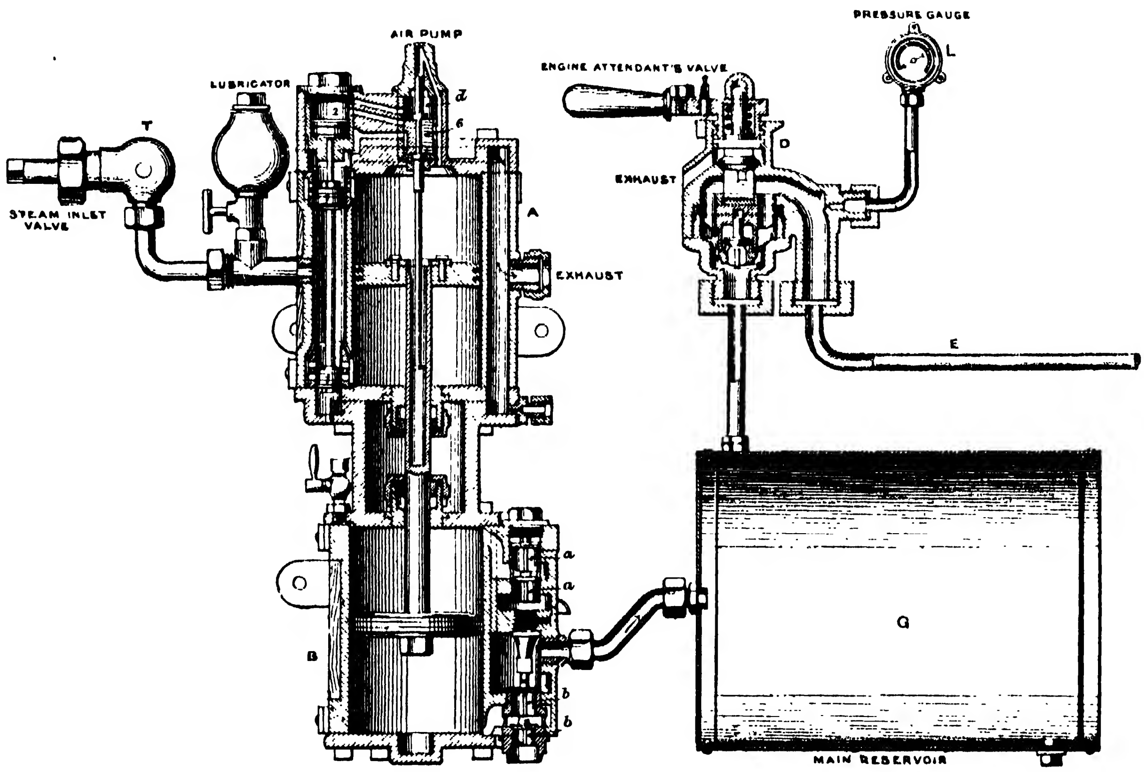

Fig. 215.—Westinghouse Compressed-air Brake Pump

the steam cylinder by means of the piston valve 1, 1, 2, the motion of which is controlled by a small pilot valve *d*, 6 in the top cylinder cover. As the compressor is of the double-acting type, pumping air into the reservoir at each stroke, the valve chest is provided with suction and delivery valves *a*, *a*, *b*, *b*, of a simple type, one pair, *a*, *b*, being fitted to each end of the compressor.

The Westinghouse Company has improved the pump by removing the vertical steam-distribution valve at the side of the cylinder, and by substituting a steam valve carried entirely in the top cover of the cylinder, which greatly facilitates inspection or replacement in case of a break-down.

Figs. 216 and 217 illustrate in some detail the arrangement of the triple valve. It consists essentially of a movable disc 3, which works on a fixed face 1, and which may be rotated by means of the controlling handle 6. The disc 3 is carried upon the squared end of the handle spindle 5. Upon the outer flange, around which the

hand lever works, are cut notches with which a small spring plunger in the handle engages, thus determining the principal positions I, II, III, IV of the valve. Suitable ports in the valve face, and corresponding passages in the disc, are provided for the

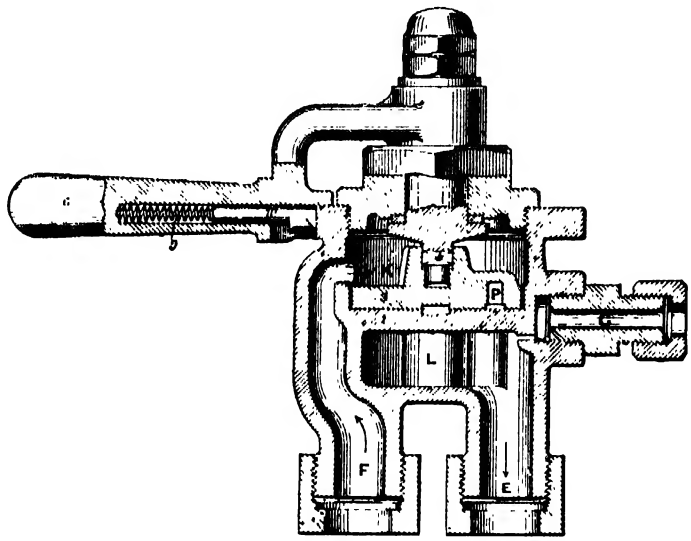

Fig. 216.—Section of Triple Valve

distribution of the air, according to the position of the controlling handle. The valve is fixed in some convenient position near the attendant, by means of the screwed pin and nut 2, fig. 217. Air from the main reservoir enters the valve through the passage F K, and communication with the train pipe takes place through E. The small connection

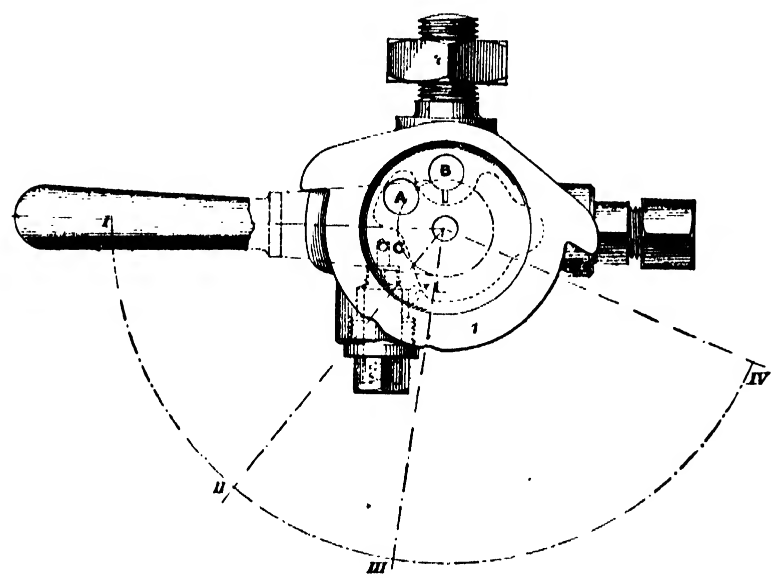

Fig. 217.—Plan of Triple Valve

G is provided for the gauge, and there is also a cock communicating with the atmosphere. Before passing through the distributor the compressed air requires to raise a lift valve, held upon its seating by a spring which ensures always a definite difference of pressure of about 2 lb. between the main reservoir and the train pipe. This difference

of pressure permits of the train pipe being more rapidly recharged after the release of the brakes, and also always ensures the existence of the pressure necessary for their release, which might not otherwise be the case, owing perhaps to a fall of the pressure in the interval.

Position I of the hand lever, the position shown in the illustration, places the train pipe in full communication with the main reservoir and withdraws the brakes completely.

With the lever at the extreme right in position IV, the train pipe is open to the atmosphere and the brakes are fully applied.

Position III is the neutral or rest position, in which all the passages are closed. It is the position after a moderate application of the brakes.

Position II is the feed position, in which the lever is placed during the running of the train. The train pipe is then in communication with the main reservoir through a very small orifice, which just permits of the passage of sufficient air to compensate the inevitable losses of pressure in the train, due to general leakage during the journey. Without this precaution there would be danger of the brakes applying themselves at unexpected moments.

Triple Valve.—The triple valve is so called because it serves three main functions:

1. To apply the brakes.
2. To release the brakes.
3. To recharge the main reservoir.

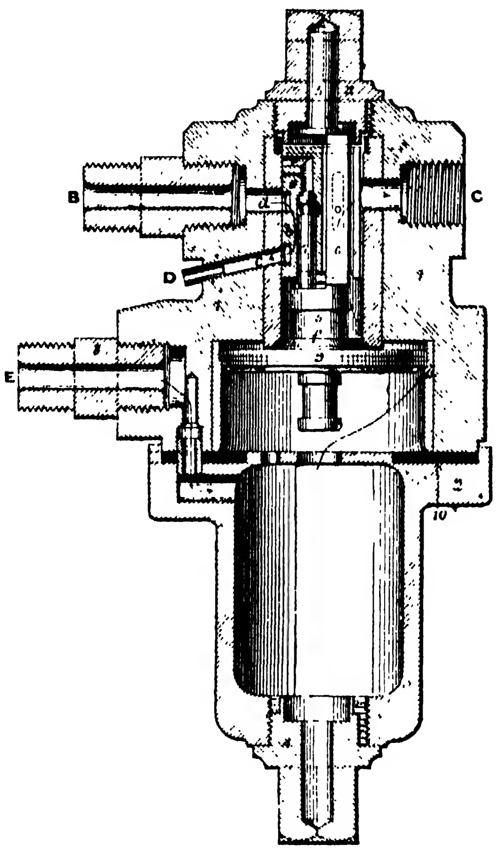

Fig. 218.—Section of Triple Valve

It is represented in section in fig. 218 which shows the upper portion 1, 1 of cast metal, fitted internally where necessary with gun-metal liners, and the lower chamber 2 to which it is secured; the joint being made air-tight by means of the leather jointing ring 10. At the top and bottom screwed metal caps are fitted, and at B and E screwed nipples are provided for the connections to the train pipe, air reservoir, and brake cylinder. B, *a* communicates with the brake cylinder, E with the train pipe, and C with the auxiliary reservoir. Inside the triple valve is fitted a working system consisting of a piston 9, provided with packing rings and mounted upon the rod 5, 5, which also carries a gun-metal slide valve 6, 6, pressed tightly against the working face by means of a spring. The slide and face are provided with the necessary apertures and channels for the distribution of the air in the various positions of the controlling lever. An opening *c*, D to the atmosphere, is provided for the exhaust.

The action is as follows:—

During the running of the train, and after the release of the brakes, the attendant

admits compressed air to the train pipe and thus to the lower chamber of the triple valve, where it acts upon the piston and immediately raises it. At the top of its travel the piston uncovers a small channel in the liner, through which the compressed air escapes into the auxiliary reservoir until the pressure there reaches that of the train pipe. During its upward travel the piston carries the small slide into the position shown in fig. 218, in which the brake cylinder is placed in communication with the atmosphere through the passages B, *a*, *b*, *c*, D. To apply the brakes the attendant reduces the pressure in the train pipe, and accordingly the pressure on the under side of the triple valve piston, which, owing to the difference of pressure on its two faces, at once falls to the bottom position, carrying with it the slider 6 into the position 2 of fig. 219. It will be seen that the large piston completely closes all communication with the train pipe, while the slide valve opens on the one hand the passage G, *a* between the brake cylinder

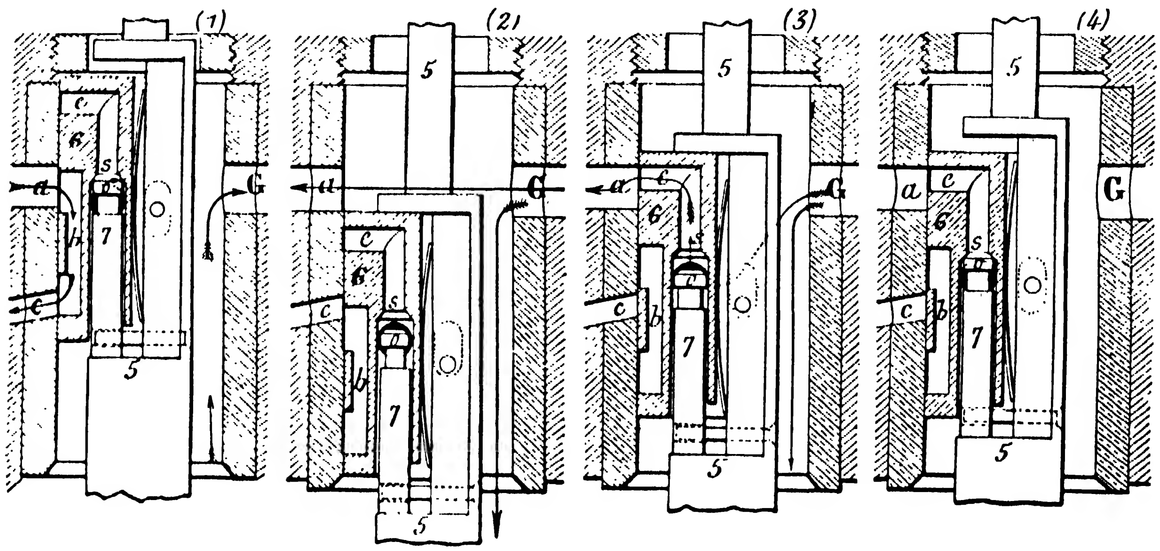

Fig. 219.—Position of Triple Valve Slide

and the auxiliary reservoir, and cuts off on the other hand all communication with the atmosphere by covering the opening *c*. Since the brake cylinder and the reservoir are now in direct communication, the resultant working pressure per square inch on the brake piston area will depend upon their respective volumes.

To again release the brakes the attendant admits compressed air to the train pipe, and as soon as the resultant pressure above mentioned is reached the large piston rises, carrying the slide valve into the running position in which the brakes are released. So far we have purposely omitted to refer to the small plunger valve 7, carried rigidly upon the piston rod 5. This plunger, which works in a channel in the slider, is fitted with a conical head and serves, when the head *o* rests on the valve seating *s*, to close the communication between the passage *e* and the opening shown dark in fig. 219. The dark orifice is carried through the slide and communicates with the space above the piston 9, that is, with the auxiliary chamber. By means of this arrangement the braking force may be varied at will. If instead of suddenly producing in the train pipe a considerable reduction of the pressure the attendant allows only a small quantity of air, not exceeding $\frac{1}{100}$ cu. ft. to escape, at a relatively slow rate, then the piston 9, instead of falling

suddenly to the bottom of its course, will sink very slowly and only fall about half way, carrying with it the slider 6 and the plunger 7; but it will only move them through half their full travel, as shown in position 3, fig. 219, in which the only communication between the brake cylinder and the reservoir is past the small valve *o* and through the narrow channel *e*. The air from the reservoir then enters the brake cylinder through this comparatively small orifice, but as soon as the pressure on the upper face of the large piston decreases it rises under the small difference of pressure, carrying with it the plunger 7 until the head *o* closes the passage *e*. The force is not, however, sufficiently great to move the slide itself, which remains where it was, as shown in position 4 of the figure. The communication between the auxiliary reservoir and the brake cylinder being closed by the extremity of the small piston, the air in the cylinder remains at the same pressure, which is, however, less than the full braking pressure, that is, the brakes are not fully but only partially applied. It will be clear that a second reduction of the train-pipe pressure effected under the same conditions will result in a repetition of the action, and the consequent entrance of a new supply of air to the brake cylinder. In this way the original pressure in the brake cylinder, and with it the braking force, will be maintained or increased. Theoretically it should be possible by successive reductions of the train-pipe pressure to bring the large piston to the bottom of its travel, and thus finally to apply the brakes with the full force. With a train of some considerable length it is hardly possible in practice to make more than two or three partial applications of the brakes, because the triple valve is sufficiently sensitive to fall completely for a reduction of 1 lb. in the train-pipe pressure. In such a case the large piston completes the full instead of a partial oscillation, the small piston valve does not play its part, and the slide is carried to the end of its stroke. The brakes thus come into action with the full force instead of in gradual stages. It is only possible to increase the braking action in this way, never to reduce it. When the brakes are released they free themselves completely.

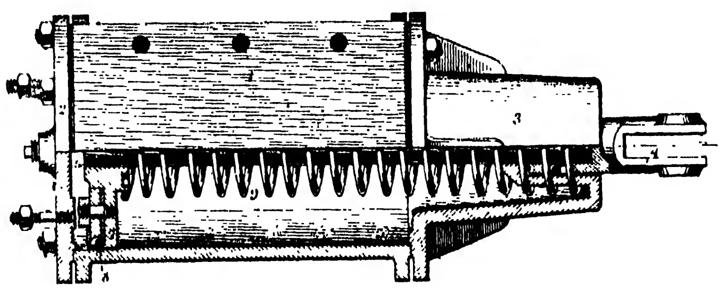

Fig. 220.—Brake Cylinder with Single Piston

Brake Cylinder.—A half section of a brake cylinder with one piston is shown in fig. 220. The body of the piston is secured to the rod 5, which is provided at the outer end with a fork to which the brake-lever system is coupled. To prevent leakage past the piston there is provided the dished leather ring 7, held in position by a junk ring and bolts. All the working parts are contained within the cylinder 1, the cover 3 which serves as a guide for the outer end of the piston rod, and the end cover into which the triple-valve pipe is connected. A strong spring 9 is provided to drive the piston back to the end of its stroke when the brakes are released. At the end of the cylinder will be noticed a small channel 8, provided as an escape for the air that may pass into the brake cylinder from the auxiliary reservoir, through some leak

in the triple valve. Unless some such escape were provided the brakes might come into action at unlooked-for moments, for although the quantity of air which escapes in this way is comparatively small, it would during the running of the train accumulate behind the piston and gradually drive it outwards until the brakes came into action.

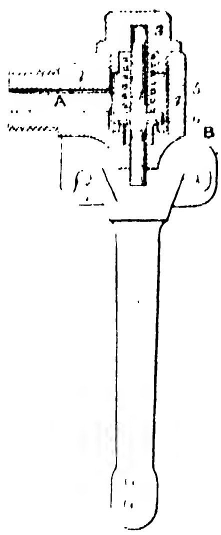

Fig. 221
Emergency Relief Valve

Emergency Relief Valve.—The valve is mounted on a T piece between the auxiliary reservoir and the brake cylinder, and consists of a small lift valve 6, held down upon its seat by the pressure of the air in the reservoir and by the spring 5. A lever 2 is suspended from pins 7 in such a way that when it is swung to one side or the other it engages with a prolongation of the valve spindle, and raises the valve off its seat sufficiently to allow the air to escape through the opening B to the atmosphere. Operating levers are connected to the arm 2 at *e*, *e*, and are led to convenient positions at either side of the vehicle. It is advisable when using the valve to hold it open until the air has completely escaped, otherwise any charge remaining in the auxiliary reservoir would pass to the brake cylinder and produce successive though more and more feeble applications of the brake.

Couplings.—In fig. 214 is shown the general arrangement of the coupling as attached to the train pipe, with the flexible tube, the head L, and the stop cock N. Fig. 222 shows the heads coupled together, the one being in full and the other in section. Air tightness at the joint between the two heads is secured by means of the flanged rubber ring, which is held in position by the three-armed piece, the stem of which butts against the screwed cap. Inclined lugs on the outsides of the heads are so arranged that when these are made to

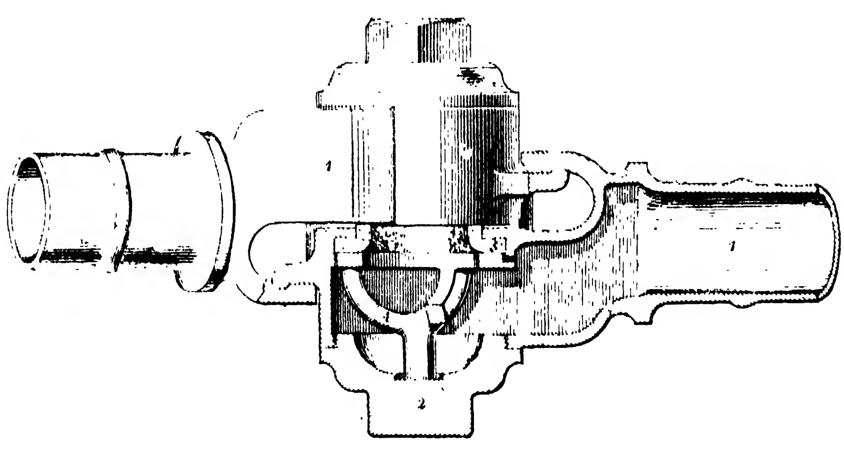

Fig. 222. Train-Pipe Coupling

engage with one another a partial rotation of the one relatively to the other will bring the rubber rings into close contact, and so make the joint sufficiently tight to withstand the air pressure.

The Westinghouse Heavy Brake.—From the description already given of the ordinary Westinghouse brake it will be seen that a certain time is required between

successive applications of the brake for the recharging of the auxiliary reservoir. If the intervals are very small the time may not be sufficient for the complete re-charging of the reservoir, so that the pressure there may gradually fall. This may, for example, occur after the descent of a long incline on which the attendant has been compelled to frequently apply and release his brakes, owing perhaps to changes in the steepness of the gradients. A large part of the track owned by the Paris-Lyons Mediterranean Railway Company in France is of this hilly description, and the same applies to the neighbouring railways of Switzerland. To meet these special require-ments the Westinghouse Henry brake, illustrated in fig. 223, is very generally used there. It consists essentially of a direct acting brake combined with the ordinary Westinghouse automatic. The brake cylinder, which is common to both systems, communicates not only with the automatic train pipe already described, but also with

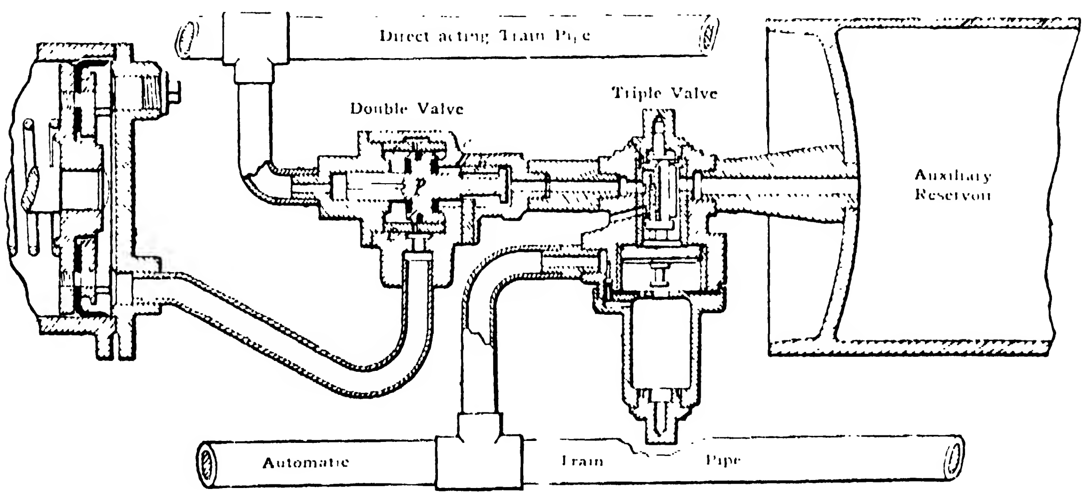

Fig. 223.—Westinghouse-Henry Brake Arrangement

a second train pipe carried throughout the whole length and provided with flexible couplings between the vehicles. Between the direct-air pipe and the brake cylinder there is placed a double valve, which serves to completely separate the two brake systems as required. It consists of a piston fitted with piston rings, and provided on its front and back faces with leather discs. The piston thus serves as a double valve. When the attendant wishes to apply the brakes by means of the direct acting gear he admits compressed air to the train pipe, which drives the double valve to the right, thus closing communication with the triple valve and opening the passage to the brake cylinder. If, on the other hand, the attendant makes use of the automatic brake, the compressed air which passes through the triple valve drives the piston of the double valve towards the left, and closes the communication between the brake cylinder and the direct-brake train pipe. The movement of the double valve at the same time opens the communication between the brake cylinder and the reservoir. A separate controlling cock is provided on the engine in connection with the direct-acting air pipe, by means of which the attendant may put the pipe into communication with either the main air-supply reservoir or with the atmosphere. In general the attendant uses the direct-acting brake for controlling the speed when running down long inclines

of varying gradient, and reserves the automatic brake for emergencies and for normal working. By using the direct brake whenever successive and frequent reduction of the speed is required, the air pressure in the auxiliary reservoir does not become impoverished, so that the automatic brake is always ready for any emergency.

Wenger Brake.—On certain of the large French railways extensive use is made of the Wenger compressed-air automatic brake, which differs considerably in its action from the Westinghouse brake. In this arrangement there is no auxiliary reservoir, and both faces of the brake piston are acted upon by the air pressure instead of only one face, as in the previous arrangements already described. Differences of pressure on the piston faces cause it to move to or fro as the case may be, and thus to apply or release the brakes. In fig. 224 are shown the essential parts of the brake as fitted upon each vehicle. In front of the brake piston is the cylinder reservoir, and between it and the

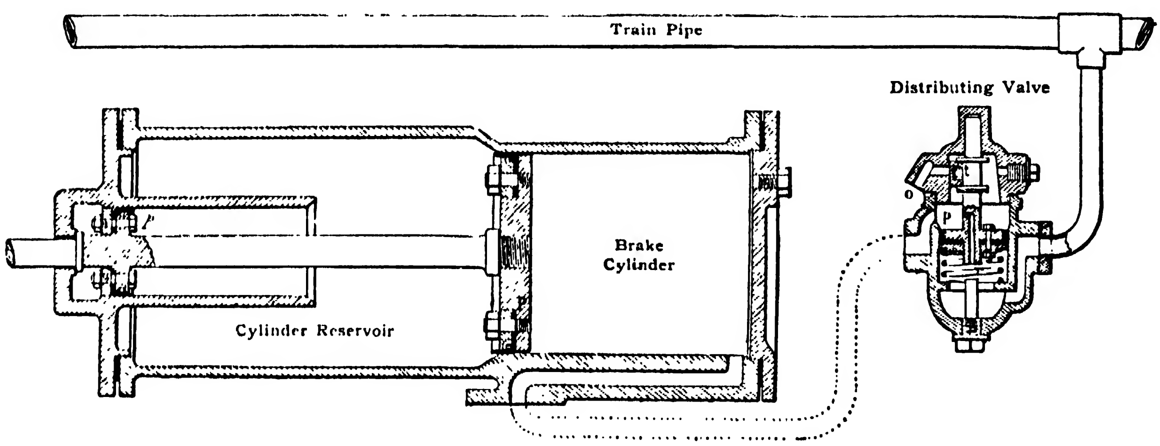

Fig. 224.—Wenger-Brake Arrangement

train pipe is placed a distributing valve of a very simple kind. The train pipe, as before, is carried along the train, and connected between the vehicles by flexible couplings. Motion of the piston in its cylinder operates the brake levers coupled to the outer end of the piston rod. To prevent leakage from the cylinder reservoir, and for another purpose described below, the rod is provided with a small piston and cup leather *p*, which work in a trunk forming part of the outer cover.

The action is as follows. During the running of the train, with the brakes in the off position, the compressed air admitted to the train pipe passes through the distributor into the brake cylinder, and escapes past the cup leather of the brake piston into the cylinder reservoir. It will be noted that, owing to the edge of the cup leather being directed away from the brake cylinder, the compressed air is able to escape from the brake cylinder to the reservoir but cannot pass back. When the pressures in the two chambers become equal, the brake piston moves out towards the left, because although the pressures on the large piston faces are equal and balance one another, there is still the pressure on the small piston unbalanced by the atmosphere on its outer face. To stop the train or to reduce the speed the attendant lowers the pressure in the train pipe, which causes the distributor to open the brake cylinder to the atmosphere. The air stored in the cylinder reservoir then drives the large piston back, and so releases the

brakes or reduces their action as the case may be. The arrangement of the distributor is such that after a moment it again closes the communication between the brake cylinder and the atmosphere, thus limiting the braking action due to the difference of pressure on the two faces of the piston. The force with which the brakes are maintained depends upon the extent of the reduction of pressure in the train pipe. By successive reductions of the pressure the brake cylinder may again be opened more and more to the atmosphere, and the diminished action of the brakes increased as desired. It will be seen that the braking action may be varied from zero to a maximum, the latter condition corresponding to a complete reduction of the pressure in the train pipe. To release the brakes the attendant increases the pressure in the train pipe, and as soon as the large piston reaches the balanced state, the pressure on the small piston drives it out, and thus relieves the brakes. It is possible for the attendant to raise the air-pipe pressure at once, or by successive stages, and thus to regulate the braking force. The distributor consists simply of a piston *p* working against a spring, and carrying upon its spindle a small slide valve *t* which opens and closes an opening *o* to the atmosphere. A small hole is provided through the piston, which allows a quantity of the compressed air constantly to leak past into the brake cylinder to compensate for any losses that may occur during the running of the train. It should be noted that the piston of the Wenger gear pulls the brake levers, while the Westinghouse acts by pushing. This involves a different arrangement of the brake levers to suit the difference in the direction of the motion. All cylinder-reservoir brakes, whether worked by compressed air or a vacuum, suffer from the common defect that the action is slow both in the release and in the application of the brakes. This results from the increased quantity of air to be moved each time, that is, not only the air in the train pipe, but also the air in the brake cylinder.

Quick-acting Brakes.—When the length of the train exceeds a certain amount, for example fourteen or sixteen vehicles, the action of the ordinary brake, which depends upon the filling or the evacuation of the train pipe through one small orifice of the manœuvring cock, is much too slow both when applying and when releasing it. As a result the rear portion of the train is braked or released before the forward part, the interval depending to some extent also upon the sensitiveness of the triple valves. The essential requirement of a good brake is that all the wheels should be gripped simultaneously, and with as nearly equal forces as possible. It will be evident that unless the action is simultaneous and uniform, the couplings will be subjected to severe jerking, and the vehicles and buffers to heavy shocks, which may even result in fracture of the couplings or other parts of the gear. Considering these serious defects of the ordinary brake, it is not surprising that much attention has been devoted to the development of a satisfactory rapid-acting brake.

In 1886 and 1887 the Master Car Builders' Association of America carried out a very complete series of trials with rapid-acting brakes applied to long trains, and also with arrangements for electrically operating the triple or other special valves so as to obtain more nearly simultaneous action.

The competitors were: The Westinghouse Automatic Brake Company, The Eames Vacuum Brake Company, The American Brake Company of St. Louis, The Widdfield and Button Company of Uxbridge, and the Rote Brake Company of Mansfield.

Each Company submitted for trial a train of 50 goods wagons, each of 40 tons capacity, fitted with their apparatus. After exhaustive tests the committee arrived at the following very definite conclusions, which have never since been seriously questioned:—

1. For long trains the best type of brake is one operated by air, and with its valves moved electrically.
2. Such a brake should satisfy the following four requirements:—
   (*a*) It should stop the train in the shortest possible distance.
   (*b*) It should reduce to a minimum the shocks and wear to which the rolling stock is subjected.
   (*c*) Release of the brakes should take place instantaneously.
   (*d*) It should be possible to adjust the pressure of the brake shoes to any degree.

The Electro-pneumatic Chapsal brake completely satisfied all these requirements, but the system of electric control has not met with the favour that might be expected, considering the advantages which it offers. Most probably the reasons for its non-adoption lie in the complication of the gear involved, and in the difficulty of keeping such electrical apparatus in good order, especially considering the conditions of continuous vibration and exposure to the weather. It is a question entirely of practical experience. More recently the question of electric control has been revived, particularly in Germany, where an improved Chapsal brake has been tried with considerable success. It seems certain that when the apparatus is developed and made sufficiently strong the system will be more generally applied, since without such an arrangement the problem, particularly in the release of the brakes, presents many difficulties. It is not possible in the limits of this brief study of the subject to enter into details of the arrangement, which consists essentially of a number of electromagnets connected by line wires to a controlling switch on the engine. One of these electromagnets is fitted to each air valve throughout the train, so that when the current is passed through the magnets the valves are simultaneously operated, and the brakes applied together and uniformly. One ingenious feature of the Chapsal brake consisted in the use of a polarized armature in place of the ordinary electromagnet. By reversing the current through the armature coils the armature could be made to move forwards or backwards as the case might be, and so close or open the braking or the release valves to which it was connected by suitable lever arrangements. With these few remarks, the subject of electrically controlled brakes must be left. In the next section the Westinghouse Quick-acting Compressed-air Brake, which to-day is in general use, will be described.

The Westinghouse Quick-action Compressed-air Brake.—The quick-acting brake is a development of the Westinghouse ordinary type, and is obtained by a simple modification of the triple valve. All the essential parts remain unaltered with the exception of the triple valve, for which is substituted a special rapid-action valve.

In practice the various parts of the gear, the brake cylinder, auxiliary reservoir, and valves, are combined so as to form one rigid and self-contained piece which may be more readily installed upon the vehicles.

In fig. 225, which shows the general arrangement, H is the brake cylinder, with its bypass channel *n*, and the piston-rod head R. G is the auxiliary reservoir; J is the relief valve; F is the rapid-action triple valve with the isolation stop-cock lever Z, which, as will be seen, serves the further purpose of suppressing when desired the rapid-action feature, or of changing from the ordinary to the quick-action condition. E is the train pipe, with the stop cock N and the coupling head K, and T represents the blow-off cock, placed, together with the pressure gauge S, on the vehicle for the purpose of testing the brakes

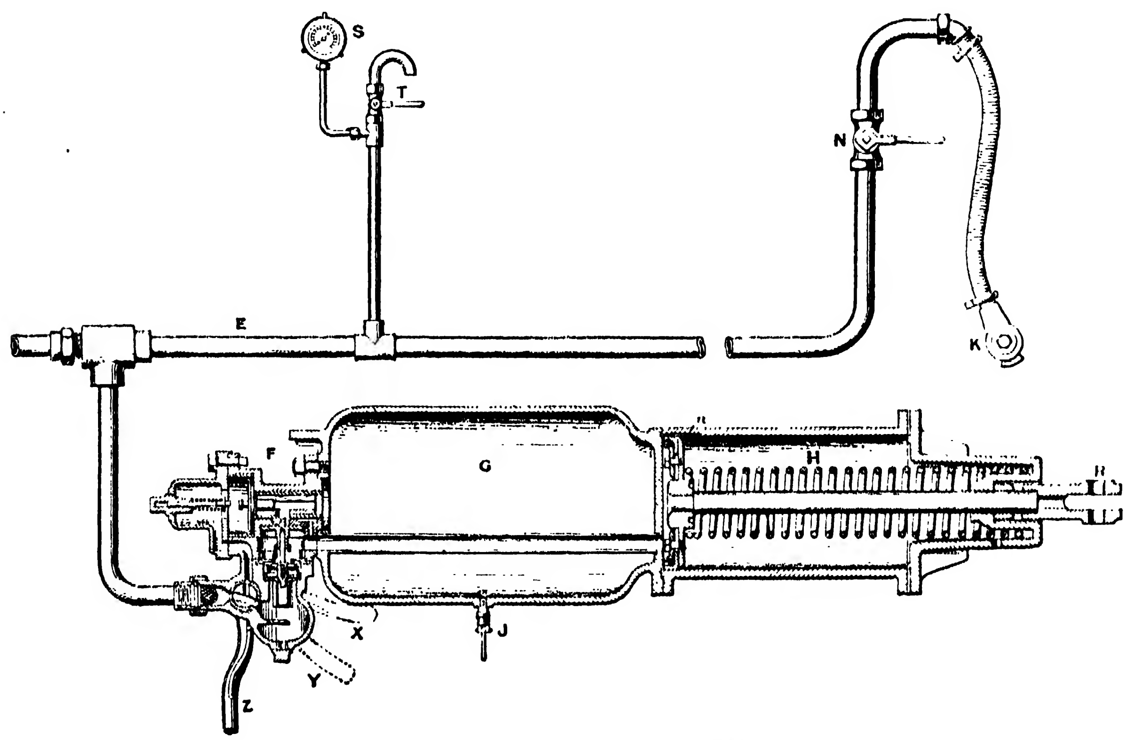

Fig. 225.—Westinghouse Quick-acting Compressed-air Brake

before the departure of the train, or for applying the brakes during the running of the train by blowing off the air in the train pipe.

Quick-acting Triple Valve.—As will be seen from the sectional view, fig. 226, the arrangement consists of the ordinary triple valve placed horizontally, combined with a second vertical valve called the accelerator. The valve is connected with the train pipe at D, with the brake cylinder at B, and at C with the auxiliary reservoir. Near the connection to the train pipe is placed a three-way cock which, according to the position of the lever, changes the brake to quick-acting or to ordinary working, or serves in case of emergency to completely isolate the brake gear upon the vehicle, while leaving the train-pipe communication clear from end to end.

The action of the gear is as follows. When the attendant wishes to make an ordinary stop, or to apply the brakes with moderate force, he slightly reduces the pressure in the train pipe by means of a special equalizing discharge cock, which it is unnecessary to explain in detail here. The piston of the ordinary triple valve moves towards the right, but not to the end of its travel, and therefore only displaces the small secondary piston and the slide sufficiently to allow the compressed air from the auxiliary reservoir

to pass through the passage *c, a, a* into the brake cylinder. The travel of the small piston and the slide is limited, as already described in the case of the ordinary triple valve, by the fall of the pressure on the left face of the large piston, resulting from the passage of the air from the reservoir to the brake cylinder. As soon as this pressure falls slightly below that of the air pipe the large piston moves back towards the left, and closes the small piston valve but does not displace the slider. In this way, by repeating these operations, the attendant is able to vary at will the braking force from zero to the maximum, without bringing into play any portion of the accelerator. If, on the other hand, the attendant wishes the brakes to act quickly, as, for example, when the train is long or when a sudden stop is necessary, he produces in the train pipe a sudden and considerable reduction of the pressure, which immediately drives the piston to the extreme right end of its travel, and with it the secondary piston and slide. Compressed air from the auxiliary reservoir then passes through the opening *h* to the upper side of the accelerator piston, which immediately falls and opens the valve 18 on the spindle 17. At the same time the compressed air in the train pipe raises the valve 19 and passes through the open valve 17 into the brake cylinder. From this there results a twofold effect:

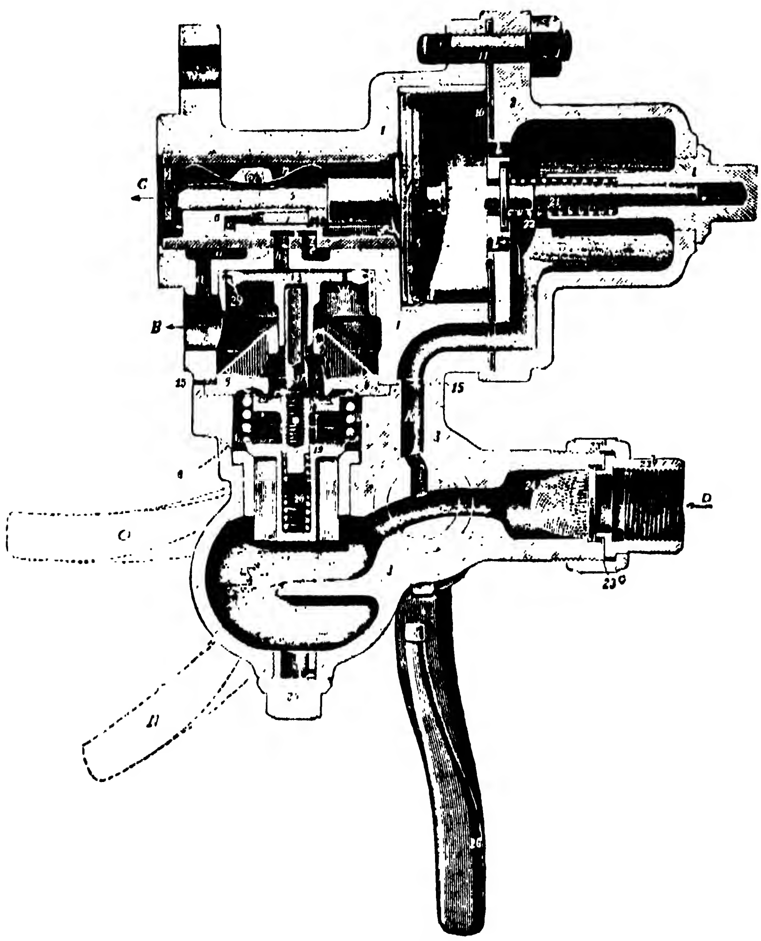

Fig. 226.—Quick-acting Triple Valve. Section

1. The air corresponding to the portion of the train pipe under the vehicle passes into the cylinder, and does work there in braking the train.
2. By the transference of this air to the brake cylinder the pressure of air in that particular section of the train pipe is suddenly lowered, and with it the pressure in the section under the succeeding vehicle.

This reduction of pressure results in the action of the triple valve on the second vehicle, and so on successively throughout the length of the train. The result is the same as would be produced by the rapid and successive opening of the emergency cocks

under each of the vehicles, only two seconds at the most elapsing between the action of the first and last triple valves in a train of sixty vehicles. It should be noted that the air from the auxiliary valve passes at the same time into the brake cylinder through the small hole w in the accelerator piston. As soon as the pressure in the brake cylinder and the force exerted by the spring 30 together exceed the air pressure of the train pipe the valve 19 closes, and thus prevents the air in the brake cylinder from returning to the train pipe when the pressure in the former exceeds that of the pipe. To release the brakes the attendant fills the train pipe with compressed air, which drives the large piston of the ordinary triple valve towards the left, and with it the valve slide. A communication between the top of the accelerator piston and the atmosphere is thus opened through the slide and the passage *h*, with the result that the accelerator piston rises under the pressure of the air in the brake cylinder, and allows the valve 18 to close under the action of the spring 20. Almost in the same instant the slider completes its full travel, and places the brake cylinder in communication with the atmosphere, thus completing the full release of the brakes. It will be evident that the release of the brakes is not so rapid as the application of them, since it is necessary to recharge the whole train pipe each time the brakes are applied. When, however, a sufficiently large main reservoir is fitted, and the running pressure used is considerable, the rapidity of the release is sufficiently rapid for most requirements. Considering the circumstances, this question of the quick release of the brakes in the case of long trains must remain the chief stumbling block in the design of a completely satisfactory pneumatic brake. The difficulty might most readily be overcome by the use of some electrical means of control already referred to, which would operate the triple valves independently and simultaneously, and place the brake cylinders directly in communication with the atmosphere.

Extra-Rapid-Action Brakes.—If when the speed of the train is very great, say 75 miles an hour, the brake shoes are applied with the usual pressure of about 45 lb. per square inch, it has been found that the shoes do not grip the wheel tyres but only slip, as a body would on ice, without producing the desired retardation. It is only after a certain time, when the speed has sensibly diminished owing to the shutting off of the steam on the locomotive, that the brakes suddenly grip the wheels and the actual braking commences. The reason for this slipping may be more readily understood by referring to the subject of the coefficients of friction, already dealt with. Galton's experiments have also very conclusively proved the fact that the friction between the brake shoes and wheels diminishes considerably when the wheel rotates quickly, and that the force becomes almost zero when the speed exceeds a certain limit. The only remedy is to increase the pressure of the brake shoes; but this unfortunately locks the wheels as soon as the speed is reduced, so that no real advantage is gained unless the pressure is reduced sufficiently at the right moment to prevent the locking action.

Westinghouse Extra-Rapid Brake.—These requirements are satisfied in a very simple manner by the Westinghouse automatic extra-rapid brake gear, the details of which are illustrated by the figures on page 200. The essential feature is the special reducing valve fitted one to each brake cylinder.

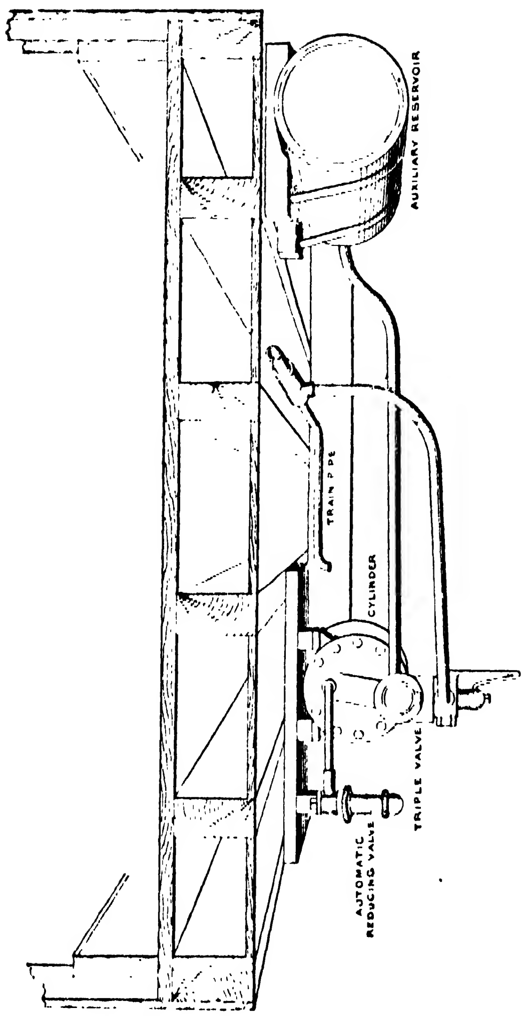

Fig. 232

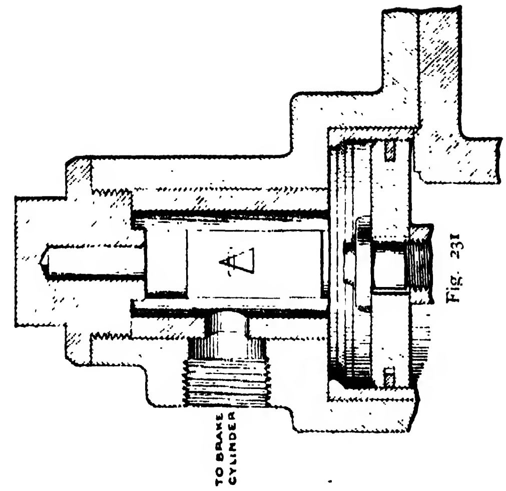

Fig. 231

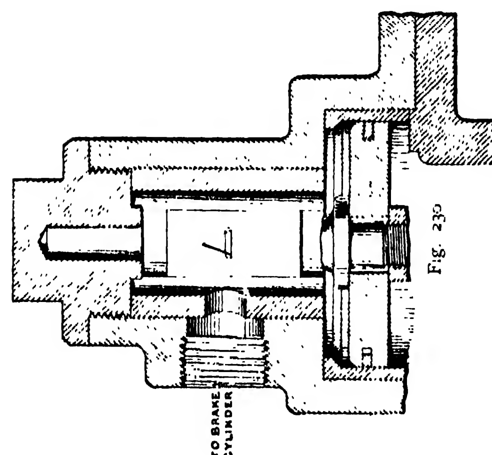

Fig. 230

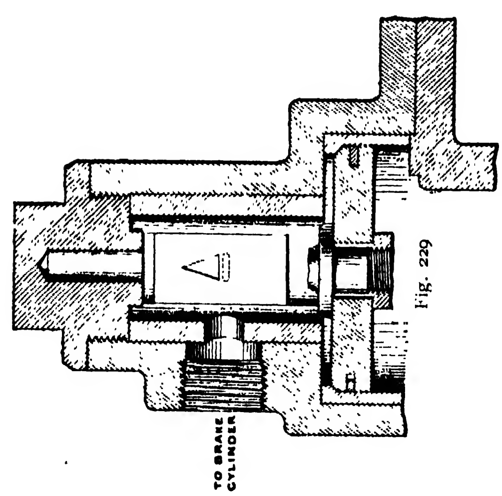

Fig. 229

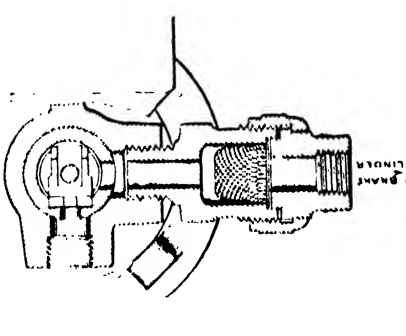

Fig. 228

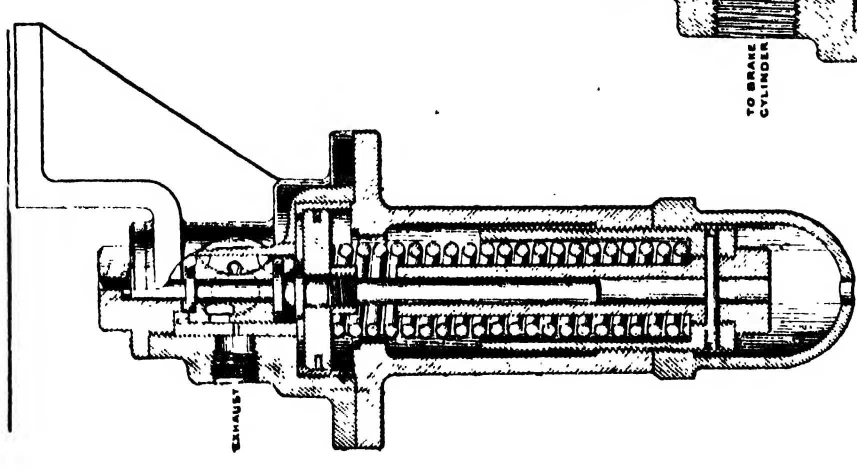

Fig. 227

Westinghouse Extra-Rapid Brake: Details of Valves and Arrangement of the Gear under the Car

Fig. 227 is a longitudinal section of the Reducing-Valve arrangement.

Fig. 228 is a transverse section through the slide valve.

The arrangement consists of a piston acted on by a spiral spring, the strength of which may be adjusted as required by means of a screwed cap. On the top of the piston rod is fixed a slide having a triangular opening which places the brake cylinder in communication with the atmosphere through the horizontal port shown in figs. 229, 230, 231. This portion of the gear is attached to the frame of the vehicle, and is connected to the brake cylinder by a pipe communication.

The action of the gear, shown in fig. 232 as actually installed under the vehicle, is of a very simple nature.

While the train is running, a pressure of 15 lb. instead of 8 is maintained in the train pipe, and consequently a working pressure of 13 lb. instead of 6 is available in the brake cylinder. Under this high pressure the piston compresses the spring, and the full breadth of opening of the triangular orifice in the slide places the brake cylinder in communication through the full breadth of the horizontal port, fig. 230. As soon as the train speed slackens, a portion of the air in the cylinder escapes to the atmosphere, and in consequence the piston rises under the action of the spring, and with it the slide. The movement of the triangular aperture before the orifice, fig. 231, gradually reduces the communication between the brake cylinder and the atmosphere from the full port opening until finally the opening is completely closed. This takes place when the brake-cylinder pressure falls from the original 13 lb. to 6 lb., but if required these limits of pressure may be varied by suitable adjustment of the spiral spring. It will be evident that the desired result has now been obtained, since the high initial brake pressure has been reduced to a normal working pressure to suit the reduced speed of the train. By these means the duration of the braking action is increased by about 30 per cent of that obtained with the quick-acting brake itself, which ensures in the case of trains running at high speeds a greatly increased factor of safety.

It is not possible here to enter further into the many details of the continuous brake. The problem is an unusually complex and difficult one, and the principles underlying it are not generally well known. It is hoped, however, that the brief descriptions given above will be of some assistance in a fuller study of the subject.

THE WESTINGHOUSE QUICK-ACTING COMPRESSED-AIR BRAKE

The large model shows in elevation the parts of the brake cylinder, triple valve, and the accelerator.
The smaller models illustrate the brake controlling gear in elevation and in plan.

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3. Back Cover of Cylinder.
4. Brake Piston.
5. Spiral Brake Spring.
6. Valve Chamber.
7. End Cover of Valve Chamber.
8. Accelerator Casing.
9. Piston-valve Cylinder Liner.
10. Three-way Controlling Valve.
11. Controlling Lever.
12. Train Pipe Connection.
13. Liner of Main Valve Cylinder.
14. Accelerator Piston.
15. Accelerator-valve Spindle.
16. Accelerator Valve.
17. Spiral Valve Spring.
18. Non-return Air Valve.
19. Main Piston Valve.
20. Valve Slider.
21. Plunger Valve.
22. Valve Spindle.
23. Air Inlet to Valve Cylinder.
24. Valve Casing.
25. Compressed-air Regulating Valve.
26. Regulating Handle.
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40. Air Passage.
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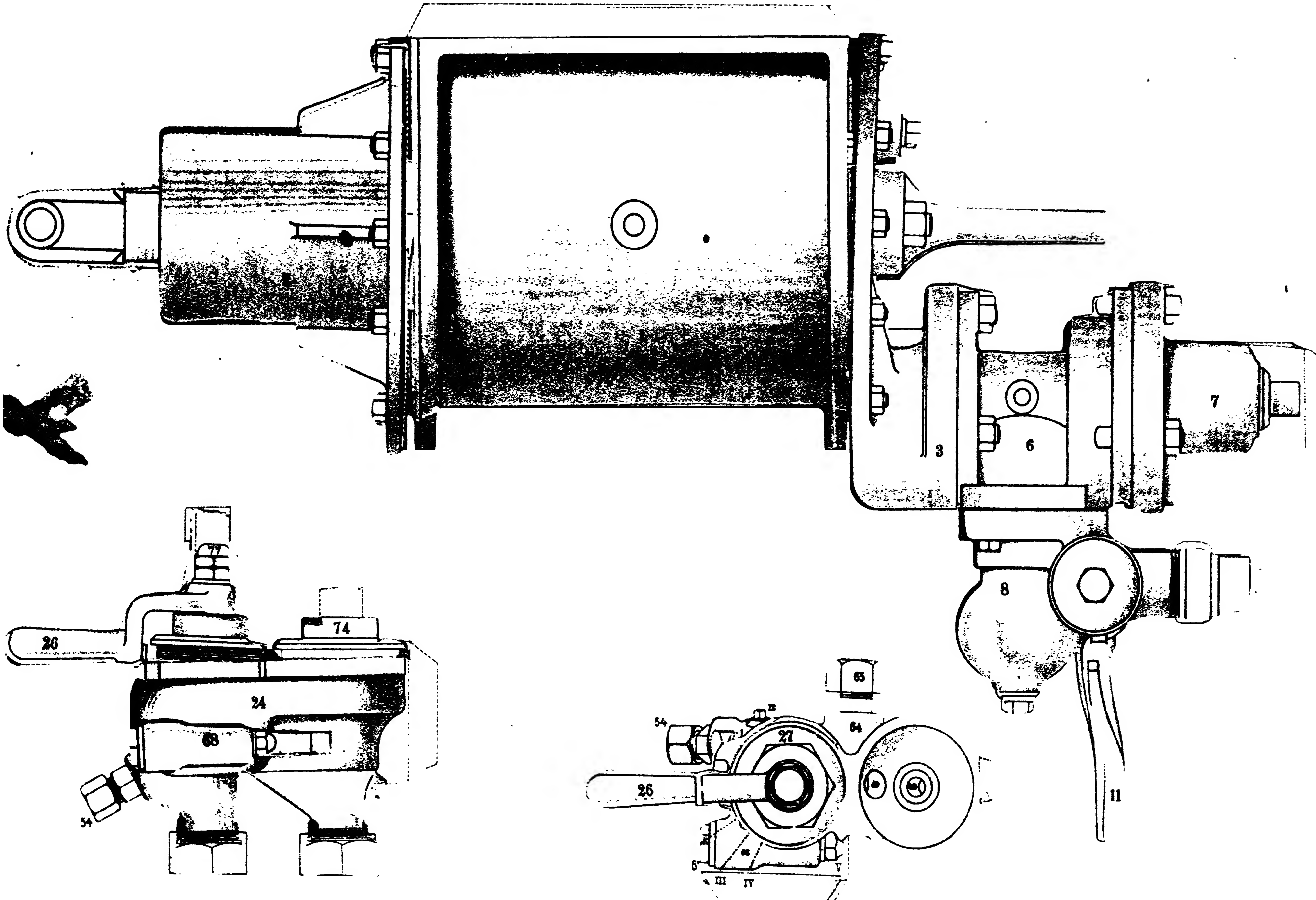
79. Squared End of Spindle.

I, II, III, IV, V. Positions of Regulating Handle.



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